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RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Surface and General Fire Control.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, covering Target O-31 of Fascicle O-1, of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Lt. Comdr. E. Delmar-Morgan, RNVR., assisted by Lt. (jg) D. H. Jackson, USNR.

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JAPANESE SURFACE AND GENERAL FIRE CONTROL

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE O-1, TARGET O-31

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

ORDNANCE TARGETS

JAPANESE SURFACE AND GENERAL FIRE CONTROL

The main bulk of this report concerns low angle (surface) fire control. The problem has been clearly known and understood for about twenty years. However, progress of science and perfecting of mechanisms has added improvements quite regularly during this period and will in all probability continue to do so.

Such progress is clear in American and British surface fire control. From the information obtained it is clear that the Japanese, too, have progressed with their surface fire; but, with one exception, they have dropped a little astern in the race. The one exception is the device for minimizing dispersion at long ranges. From examination of the device it appears to be far from perfect, to be unnecessarily complicated, and to have numerous weaknesses; but its potentialities were clearly demonstrated in the Leyte action in October 1944 and due credit must be given.

The lack of good radar in Japanese surface fire is offset to some extent under certain conditions by their excellently grouped salvos, and, in general, their surface fire is, there fore, not much inferior to that of other navies.

Japanese stable verticals and gyro work for fire control seem to be vastly inferior. Little thought seems to have been given to line of sight stabilization by small gyros with one degree of freedom, or to rate measurement by small gyros.

Finally, with reference to the mechanical and electro-mechanical torque amplifiers, it is difficult to judge performance from diagrams. They may be quite good, but the principles upon which they are based are all well-known, with the exception of the Aichi Clock Company's electro-mechanical servo.

For further information on synchros, wiring diagrams, and remote power control systems, reference may be made to NavTechJap Report, "Japanese Fire Control", Index No. O-29. For further information on anti-aircraft fire control, reference may be made to NavTechJap Report "Japanese Anti-Aircraft Fire Control", Index No. O-30.

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LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

REFERENCES

Location of Target:

Kure Naval Arsenal
Yokosuka Naval Bases
Aichi Clock Company

Japanese Personnel Interviewed:

(a) Commander Jiro ICHINOI, IJN (Ret) - Fire Control Design Engineer, 1940 - 1945, Kure Naval Ordnance Experimental Laboratory and head of Fire Control Factory. April 1945 to August 1945, attached to the First Naval Technological Institute, YOKOSUKA.

(b) Mr. TAKEMURA - Scientific adviser on research at the Naval Research Institute, Meguro, TOKYO.

(c) Mr. TSUDA - Head Fire Control Design Engineer, Aichi Clock Company, NAGOYA.

INTRODUCTION

Before a study of the Japanese naval fire control systems could be made, it was found necessary to list the Japanese descriptions of fire control equipment in Romaji. The reason for this is the great degree of ambiguity which existed unless the Japanese words are used. For instance, it is of no value to comment on a Type 94 System without further qualification since there are several such systems designed initially in 1934 for which the figure 94 is used. Hereunder is given as clear a listing as possible:

Directors

HOIBAN*	L.A. Director
KOSHAKI	H.A. Director
SHAGEKI SOCHI	Short Range Director

Computers

SHAGEKI BAN	L.A. Computer
KOSHA SHAGEKIBAN	H.A. Computer
BIODOBAN	H.A./L.A. Simplified Computer

Fire Control Systems

KOSHA SOCHI	H.A.
HOSEN SHIKI SOCHI	L.A.

The different types of directors, computers and fire control systems can now be listed as follows:

Directors

(1) L.A.

HOIBAN Type 14	Obsolete
HOIBAN Type 94	Standard for all ships except YAMATO and MUSASHI
HOIBAN Type 98	YAMATO and MUSASHI
HOIBAN Type 94 Mod 5	Converted for H.A. for AA cruisers with 12.7cm guns
HOIBAN Type 94 Mod 6	Same as Mod 5; renamed Type 2

(2) H.A.

KOSHAKI Type 94	Ship
KOSHAKI Type 3	Land

Computers

(1) L.A.

SHAGEKIBAN Type 92	40cm (16") guns in NAGATO
SHAGEKIBAN Type 94	14cm guns in NAGATO
SHAGEKIBAN Type 98	46cm (18") guns in YAMATO and MUSASHI

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*HOIBAN	HOI - Bearing Angle, BAN - board
KOSHAKI	KO - High Angle, SHA - Firing, KI - Instrument
SHAGEKI	Firing
BAN	Board or Panel
SOCHI	Equipment
KOSHA	KO - High Angle, SHA - Firing
BIODO	Deflection
HOSEN	HO - Gun, SEN - battle
SHIKI	Command

continued

(2) H.A.

KOSHA SHAGEKIBAN Type 89	H.A.	Obsolete
KOSHA SHAGEKIBAN Type 94		Present type as in YAMATO and MUSASHI

Fire Control Systems

(1) L.A.

HOIBAN 94 plus SHAGEKIBAN Type 92	As in NAGATO
HOIBAN 94 plus SHAGEKIBAN Type 94	Standard
HOIBAN 98 plus SHAGEKIBAN 98	YAMATO and MUSASHI
HOIBAN 98 plus SHAGEKIBAN 94	As in NAGATO
HOIBAN 2 plus BIODOBAN 2	Destroyers
HOIBAN 94 plus BIODOBAN 94	Destroyers

(2) H.A.

KOSHAKI 94 plus KOSHA SHAGEKIBAN 94	YAMATO and MUSASHI
KOSHA SOCHI 91	(91 mod 2) removed from NAGATO
KOSHA SOCHI 2	Ground use
KOSHAKI 3 (KOSHA SHAGEKIBAN 94)	To be renamed type 4 for ground use
KOSHA SOCHI 3 - KOSHAKI 3 and KOSHA SHAGEKIBAN 3	Ground use (computer never built because too complicated)
KOSHA SOCHI 3	Ship use (never built)
SHAGEKI SOCHI 95	Director and Computer combined (controls M.G. with Ward Leonard System)
KOSHA SOCHI 95	Ground use (complicated and obsolete)
SHAGEKI SOCHI 4	Simplified 95 (OMI KOSHI)
KOSHA SHIKI SOCHI 5	Thundercloud (RAIUN - one made but never tried)
DENTAN HOIBAN 5 plus BIODOBAN 2	Radar Director (for destroyers and Cruisers)

Enclosures (A) and (B) list the material and documents sent to the various agencies in the USA. Enclosure (C), it is hoped, will help to identify the systems with the ships concerned.

It is suggested that NavTechJap Report, "Japanese Anti-Aircraft Fire Control", Index No. 0-30, should be referred to since that report together with this report form a complete treatise on all above water Japanese naval fire control systems.

THE REPORT

Part I
TYPE 98 FIRING DEVICE FOR MINIMIZING DISPERSION

A. GENERAL

Samples of equipment for this purpose have been captured intact and it has been possible to reconstruct a circuit diagram (Figure 3). The device consists of two main items:

1. An instrument installed in the transmitting station or plotting room called a "Trigger Time Limiting Device" to limit the time of firing of two or more guns from 0.08 seconds to 0.2 seconds after the circuit has been made, thus diminishing dispersion.

2. An instrument installed in the gun turret called a "Firing Time Separator" which ensures that projectiles do not leave the guns at the identical instant of time. This prevents interference and therefore helps to diminish dispersion.

The captured equipment consists of two trigger limiting devices and one firing time separator from the battleship NAGATO, and the system is identical to those installed in MUSASHI and YAMATO. The equipments in NAGATO were fitted retroactively at the time the latter ships were being fitted out.

B. DESCRIPTION

1. Time Limiting Device

Figures 1 and 2 show these instruments, and the diagram of Figure 3 gives the main features.

The limitation of time from 0.08 to 0.2 seconds in the time limiter can be varied by selecting the correct position on the rheostat R_1 in the upper portion of the diagram. When the trigger in the director is pressed, circuit a, b, d, e, f, o, p, q and r is made; the coil O is energized, and the iron core pulled up. Xy is now in a short circuited condition and the firing circuit x, y, c, d, e and f remains closed (since no current is now flowing in the circuit a, b, c, x and y, there will be no arcing of the contacts in the pistol when the trigger is released).

The motor M_1 will now rotate and the electromagnet Z will be energized and the circuit "de" will be broken. The time between first pressing the trigger "b" and the rupture of the circuit at "de" constitutes the correct time interval (more correctly it is the period of time that begins with the rotation of M_1 and ends when the contact is broken). The duration of the firing circuit continuity is therefore independent of the length of time the trigger is pressed.

2. Firing Time Separator

Until both the windings A and B in the rotor S are excited there is no rotation of the rotor. The rotor turns against a spring force which positions it in a certain set position when there is no other torque upon the rotor. When rotor S rotates, the contacts S_1, S_2, S_3, S_4 and S_5 are made. In the same way, the rotation of R accomplishes the same function with respect to r_1, r_2, r_3, r_4 and r_5 and of T to t_1 and t_2.

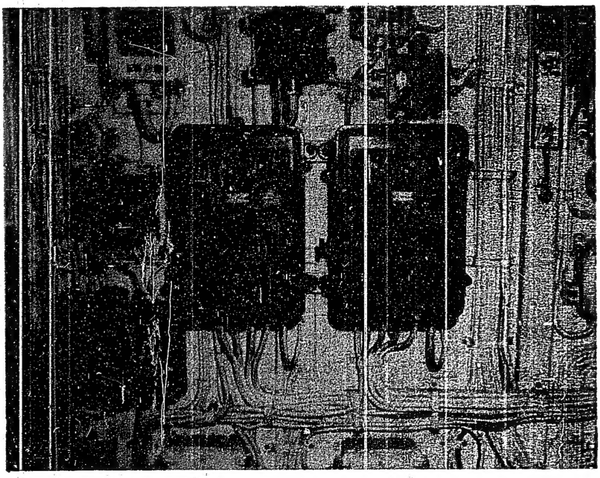


Figure 1
TIME LIMITING DEVICE

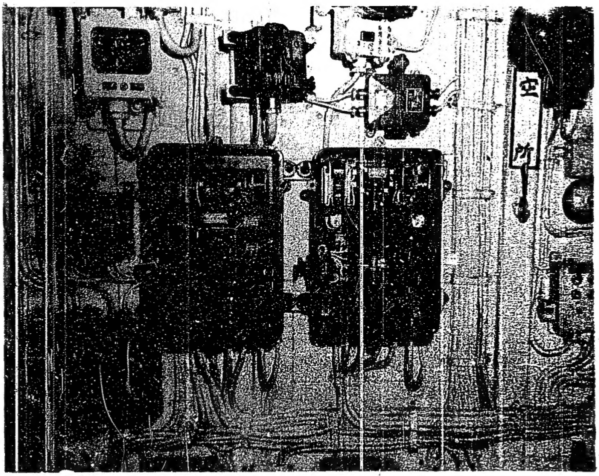


Figure 2
TIME LIMITING DEVICE - COVER OPEN

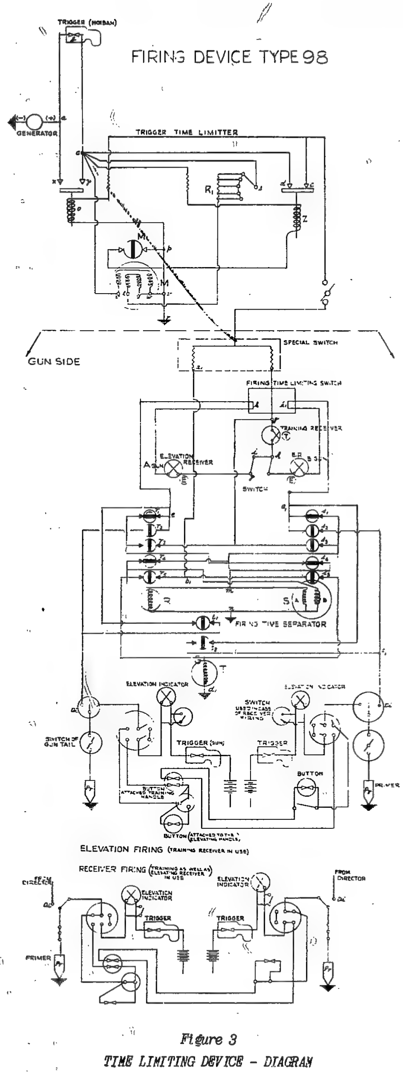


Figure 3

TIME LIMITING DEVICE - DIAGRAM

When the firing circuit in the time limiter is made, and when the pointers are matched in the training receivers (there is a contact device in each receiver for allowing the guns to fire only when the pointers are matched), "A" gun (on left of diagram) will fire due to the completion of the circuit abc (or axyc) d e f g T h i j E k l r_1 S_4 m R n; alternatively, when r_5 is making contact, circuit a_1 b_1 r_5 e_1 d_1 rotates rotor T by means of the contactors t_1 and t_2.

"B" gun (on the right) will fire only when the elevation receiver has both pointers in coincidence (identical with the training situation), so "B" gun fires just after the interval required for t_2 to rotate after "A" gun fires.

Therefore, when the pointers in both elevation and training receivers coincide and complete the circuits, current will flow both in A and B of rotor S, in which case S will remain stationary, R will rotate and the sequence of operations will occur as just described; "A" gun will immediately fire, followed by "B" gun. In addition to director firing as described, the guns can be fired in local firing when the pointers match.

Part II
SURFACE AND GENERAL FIRE CONTROL

A. TYPE 92 MAIN LOW ANGLE FIRE CONTROL TABLE (SHAGEKIBAN) AND TYPE 94 LOW ANGLE DIRECTOR (HOIBAN)

1. General

The Type 92 Main Low Angle Table for battleship (as in NAGATO) and heavy cruisers (except MOGAMI class) is associated with the Type 94 Main L.A. director for the control of the main armament.

There are two kinds of Type L.A. Table and these are distinguished on paper only by stating that they are prepared for two classes of ships: (a) battleships and heavy cruisers, and (b) the MOGAMI class.

The Type 92 in class (b) above have mechanisms incorporated for measuring target speed and target angle and require an input only of inclinometer angle. In addition, they have corrections to range for wind along the line of fire.

The Type 92 in class (a) lacks these devices and instead has a device called a SOKUTEKIBAN which looks much like a director (see Figure 4) and contains mechanisms for calculating target course and speed to be transmitted to the L.A. table. At the end of this chapter is a brief description of this SOKUTEKIBAN.

The Type 92 L.A. Table and to a lesser degree the Type 94 L.A. director bear a remarkable similarity to the British Main L.A. tables of about 1924.

The Aichi Clock Company who manufactured all the L.A. tables state that Barr and Stroud of Glasgow provided them with the general pattern over a course of many years and they have continued ever since to adhere to this pattern.

2. Type 92 L.A. Table (SHAGEKIBAN)

a. This table is manufactured for the following ballistics:

36cm/45 cal gun	20cm/50 cal (Mark 2) gun
40cm/45 cal gun	15.5cm/60 cal (obsolete) gun

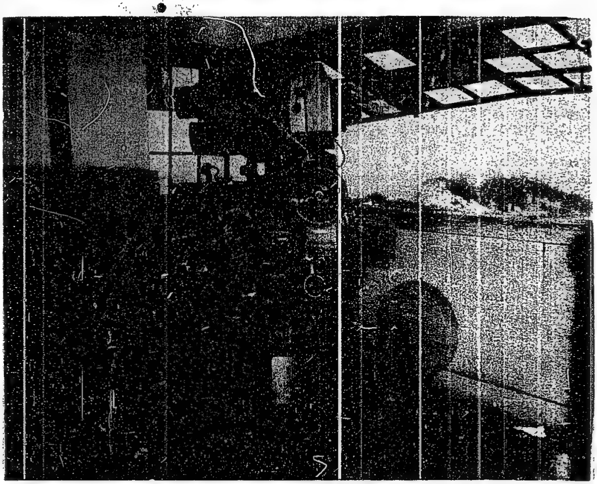


Figure 4
Type 92 SOKUTEKIBAN

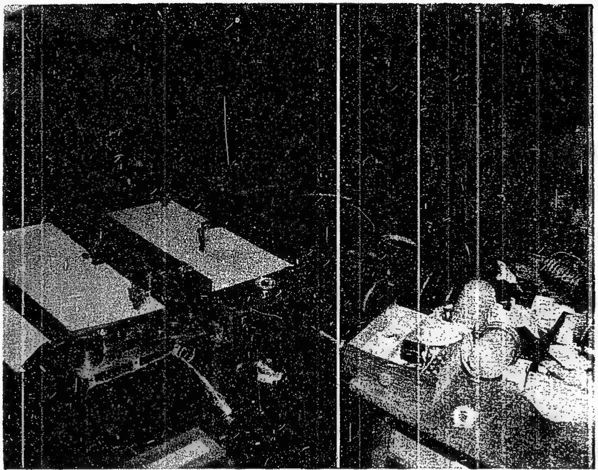


Figure 5
TYPE 92 K.A. TABLE (SHAGEKIBAN)

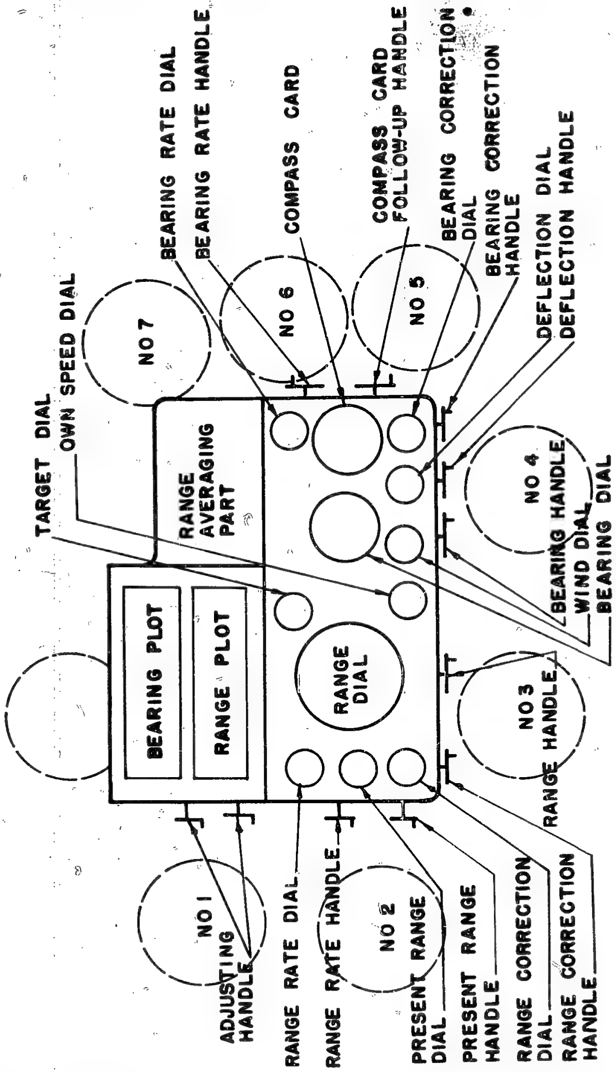


Figure 6
TYPE 92 L.A. TABLE (SHAGEKIBAN)

The table calibrated for 40cm guns (16") is shown in the transmitting station of NAGATO in Figure 5, and Figure 6 gives a plan view of the table showing the layout and the position of the seven operators and the control officer.

b. Duties of the personnel

Operator No. 1	Supervises and operates the range and bearing plots.
Operator No. 2	Turns the range and range rate ($\frac{dR}{dt}$) handwheel at his right and left hand respectively, so as to match the range indicated by the control officer and range rate from the slope of the range plot by matching pointers.
Operator No. 3	Follows up future range.
Operator No. 4	Sets initial bearing angle (B), total deflection correction to bearing (in the case of indirect fire) setting of own ship's speed, target speed and target inclination.
Operator No. 5	Follows up compass course as received from the gyro compass.
Operator No. 6	Follows up bearing rate from the bearing plot.
Operator No. 7	Range averaging man. This operator observes the ranges received from the different range finders (five in NAGATO), cuts out those which are either inoperative or inconsistant and provides the selected range for the range plot.

c. Limits of the Type 92

Measured range	40,000 meters
Deflection in mils	Right 130, Left 160
Own speed	30 knots
Enemy course	90° right or left
Firing range	39,800 meters
Change of range	70 knots
Enemy speed	40 knots
Wind speed	20 meters/sec

d. Size and Weight

Width	1.8 meters
Length	1.5 meters
Height	.9 meters
Weight	3.5 metric tons

e. Functions - The schematic diagram, Figure 8, shows the general functions of the Type 92, which is known as the "reciprocal" type, since the calculated values of super elevation and lateral deflection are transmitted to the Type 94 director (HOIBAN) where they are added differentially to director setting and director training. Quadrant elevation and gun training are then transmitted to the guns (after the quantities for parallax and corrections for roll and cross roll have been added) as shown in Figure 7.

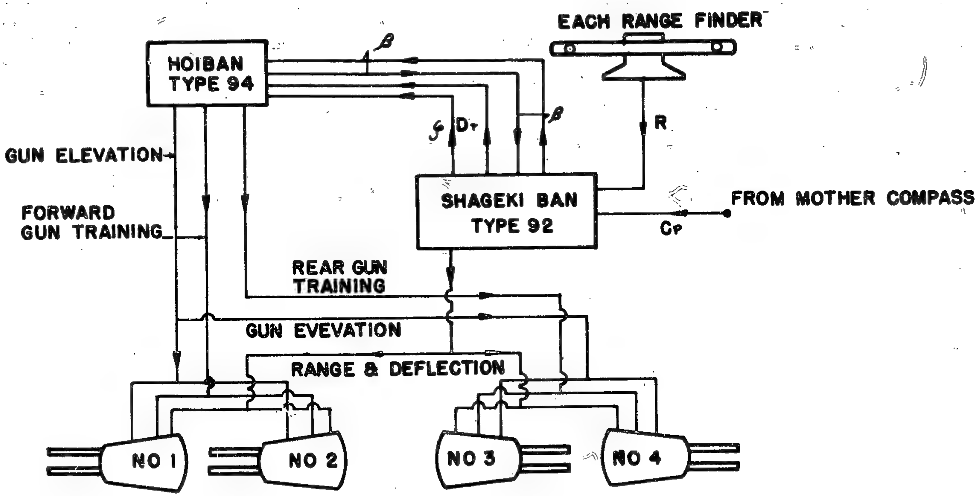


Figure 7
TYPE 92 L.A. TABLE AND TYPE 94 DIRECTOR

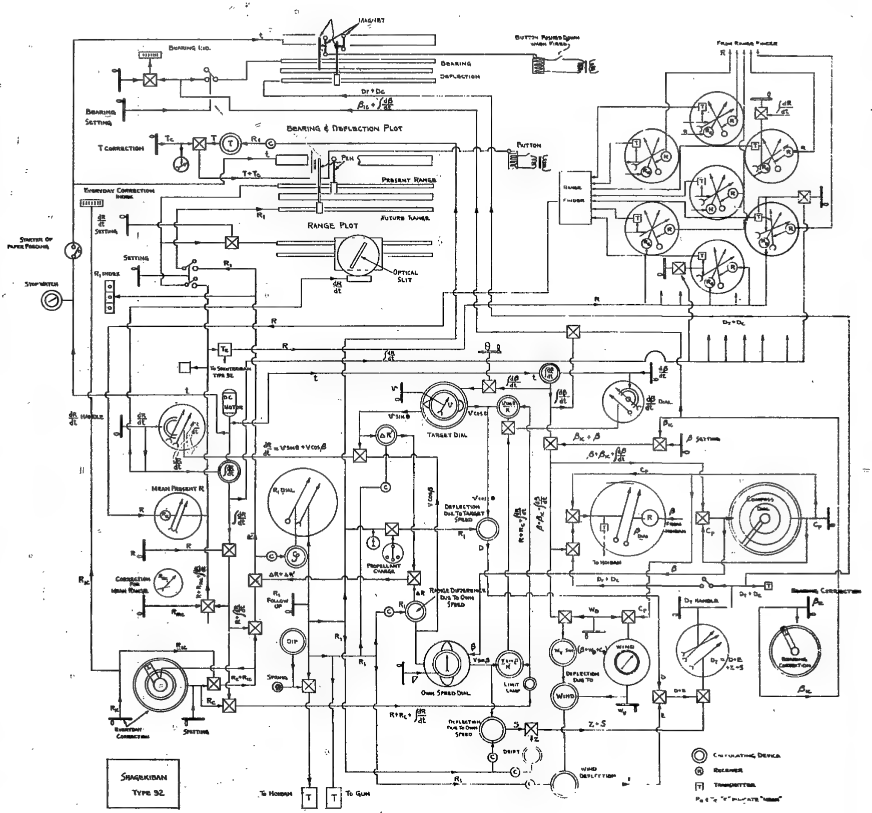


Figure 8

TYPE 92 L. A. TABLE DIAGRAM

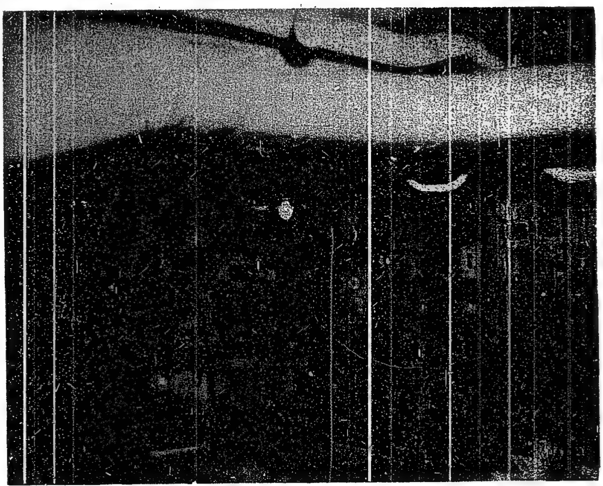


Figure 9
GENERAL ARRANGEMENT OF
PLOTTING ROOM ABOARD NAGATO

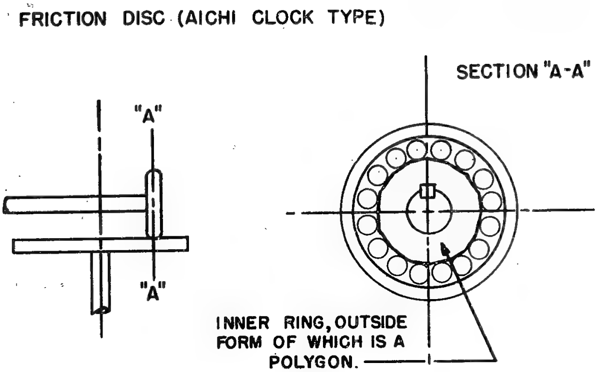


Figure 10
"POWER" RATE INTEGRATOR DIAGRAM

f. Calculated Values

(1) Lateral Deflection D_T

$$D_T = D + E + Z + D_W + D_c$$

Where D = own speed correction
E = target speed correction
Z = drift correction
D_W = wind correction
D_c = spotting correction

(2) Super Elevation

$$\phi = f(R_1) + \text{dip}$$

Where R_1= future range

$$R_1 = R_o + \int \frac{dR}{dt} + \Delta R + \Delta R' + R_{1c} + R_c$$

Where R_o= initial range and $R_o + \int \frac{dR}{dt}$ is present range
$\int \frac{dR}{dt}$ = output of integrator
R = own speed correction
R'= target speed correction
R_{1c} = ballistic corrections for the day
R_c = spotting correction

(Note : Correction for wind is to deflection only and not to range.)

g. Mechanisms - There are no pneumatic, hydraulic, or electric follow-ups in the table. There is one mechanism of interest and this is a "Power" Rate Integrator. The "power" rate integrator is shown in Figure 10. This mechanism consists of a hardened steeldisc which is held by considerable pressure against the constant speed disc. There are special devices incorporated in the L.A. table to prevent this disc being moved unless the constant speed drive is switched on, since damage would immediately result otherwise. Although the principle is simple, the details are not. It was discovered by trial and error that the best results were obtained when there was a small amount of backlash between the disc and the shaft to which it was attached. The backlash was not just a crude backlash as between a key in a keyway, or a sloppiness in a loose fitting spline, but was a variable backlash according to the load. This was obtained by making rollers between the outer disc and the center member have a wedging action between the circular outer ring and the flats of the polygon shaped shaft. This arrangement works very nicely when the disc is nearly or actually at the center of the constant speed disc, and then a very smooth action results. It might be described as a "velvet" hunting action.

h. Production - The first unit of the Type 92 L.A. table was produced in 1932 and the last one in April 1943. The Aichi Clock Company's capacity was stated to be one per month and the cost ¥ 150,000.

3. Type 94 L.A. Director (HOIBAN)

a. This is the regular director associated with the SHAGEKIBAN Type 92. The Range Follow-up, Range Setting and Deflection Follow-up side is shown in Figure 11. The general arrangement of the personnel and their functions are given in Figure 12, and are as follows:

Operator No. 1 Layer
Operator No. 2 Trainer
Operator No. 3 Cross leveller
Operator No. 4 Deflection and super elevation follow-up
Operator No. 5 Communications man
Operator No. 6 Control officer

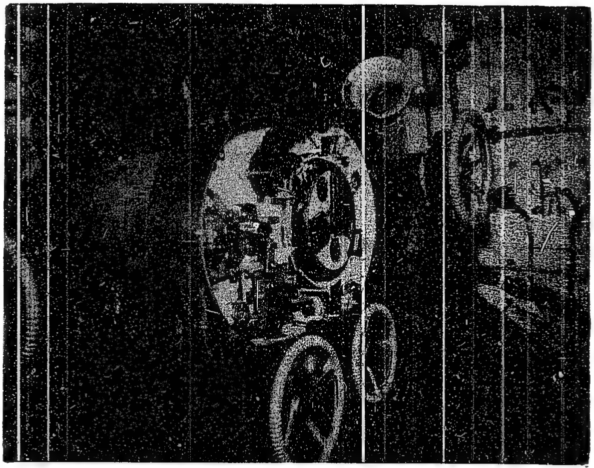


Figure 11

TYPE 94 DIRECTOR (HOIRAN)

This director is used for controlling either main or secondary armaments and is the conventional bi-axial director. There are two calculating devices in this director; one for roll in the line of sight and cross roll corrections to elevation and training, and one for parallax.

The telescopes for layer, trainer, and control officer for main battery control are 15cm, and for secondary batteries and main armament of cruisers, 12cm (the cross leveller's telescope being 4.5cm in all cases). As already mentioned, the "reciprocal" arrangement of the system requires hand follow-ups for deflection and super elevation in the director.

b. Limits of operation

Maximum elevation	45°
Maximum depression	12°
Maximum roll	10°

c. Size and Weight

Height	1.7 meters
Width	1 meter
Operating radius	1.5 meters
Weight	2 metric tons

d. Functions - The diagram is self explanatory, but it should be noted that in the latest ships a stable vertical (gyro) was installed in the transmitting room and transmission of roll and cross roll were provided to the director where they were hand followed-up by matching pointers; this was particularly for night when no horizons were visible.

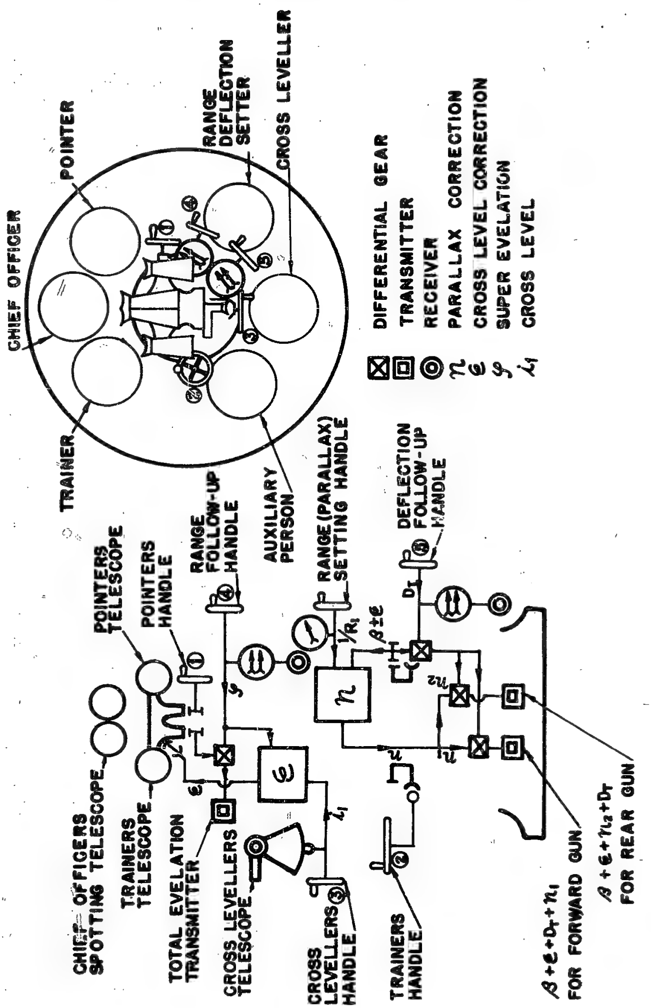


Figure 12

TYPE 94 DIRECTOR (HOIBAN) DIAGRAM

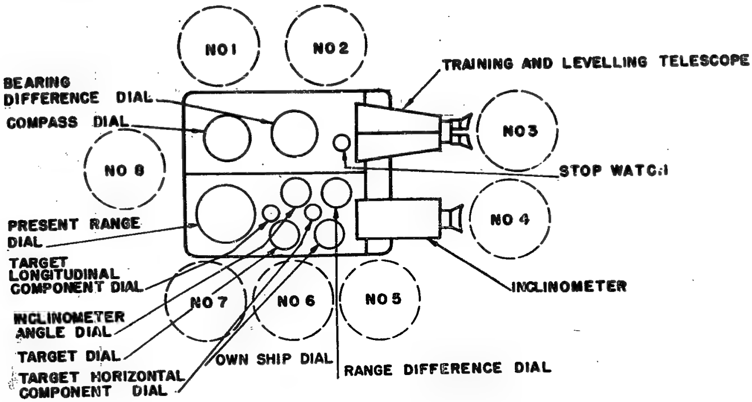


Figure 13
TYPE 92 SOKUTEKIBAN LAYOUT

"Dip" is calculated in the SHAGEKIBAN and transmitted with future range to the director and thence to the guns.

e. Production - These directors were made at Kure Naval Arsenal. About 132 in number were made between December 1943 and April 1945. Approximate cost (less optical parts) was ¥ 10,000 each.

4. Type 92 SOKUTEKIBAN (See Enclosure D)

a. Since there is no good English equivalent for the name of this device, the Japanese word will be used throughout. The instrument is designed to provide transmissions of target speed and target course to the L.A. table (SHAGEKIBAN). In appearance (see Figure 4) it is somewhat like a director and has to be layed and trained like a regular director. Figure 13 shows the layout; the duties of the personnel are as follows:

Operator No. 1	Compass follow-up
Operator No. 2	Enemy change of bearing
Operator No. 3	Trainer
Operator No. 4	Inclination
Operator No. 5	Target length setting and range difference setting
Operator No. 6	Inclinometer angle follow-up
Operator No. 7	Present range follow-up
Operator No. 8	Target speed and target angle follow-up transmission

b. Size and Weight

Height .... 1.75 meters

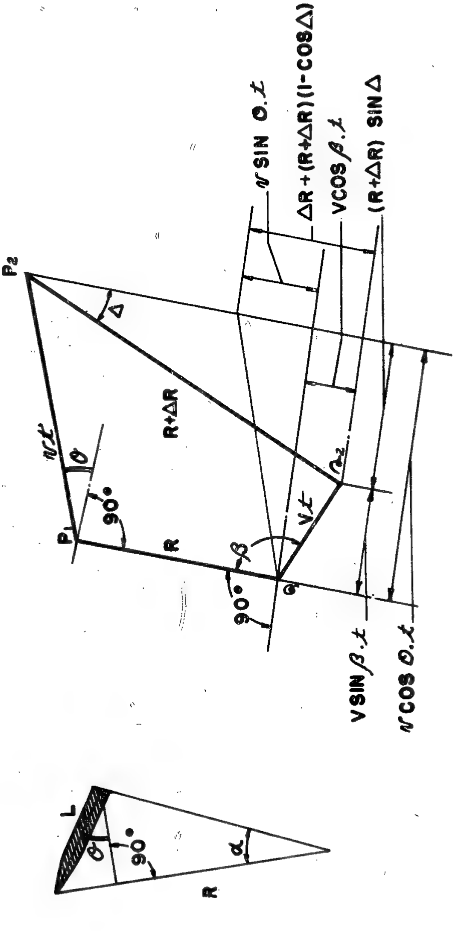


Figure 14
TYPE 92 SCRUTERTRAN VECTOR DIAGRAM

Width .... 1.25 meters
Operating radius .... 1.5 meters
Weight .... 2 metric tons

c. Principles of Calculation

$$\alpha = \frac{L \cos \theta}{R} \quad - - - (1)$$

Where θ = Target angle
L = Length of ship
R = Present Range
α = Inclinometer Angle

After an increment of time "t", the following is the situation as shown on the vector diagram in Figure 14.

$$(V \sin \theta + V \cos B)t = \Delta R + (R + \Delta R)(1 + \cos \Delta) - (2)$$

$$(V \cos \theta - V \sin B)t = (R + \Delta R) \sin \Delta - - - - - - - (3)$$

Where P_1 = Present position of target
Q_1 = Present position of own ship
P_2Q_2 = Position of own ship and enemy, t seconds later
t = Time increment
Δ = Bearing difference after the elapsed time of t seconds
ΔR = Range difference after elapsed time of t seconds

When an inclinometer is used, the angle can be measured and equations (1) and (3) are solved.

When an inclinometer is not used, equations (2) and (3) are solved. Rate mechanisms are used for this calculation and a constant time mechanism also (clock escapement) for spacing the two sets of readings by a time interval of t.

All these SOKUTEKIBANS were made by the Aichi Clock Company of NAGOYA.

B. TYPE 94 LOW ANGLE FIRE CONTROL SYSTEM SHAGEKIBAN TYPE 94 AND HOIBAN TYPE 94

1. General

This fire control system is installed in capital ships for controlling the secondary armament and in light cruisers for the main armament. In Figure 15, of BB ISE, the forward director at "X" can be seen just below the radar antennae and rangefinder, shown separately in Figure 16. A view looking aft (Figure 17) shows the after director at "X". It is interesting to note in Figure 17 that the after turrets have been removed and a hanger has replaced them, and that the hanger deck shows a cutout in airplane shape for the elevator.

The system as a whole, and the clock or computer (SHAGEKIBAN) in particular, (as seen in Figure 18) is similar to the British Admiralty Fire Control Clock. There are, however, two distinct differences:

a. The Japanese clock has a range plot.

b. The Japanese clock is semi-tachynetric in principle.

The system belongs to the "series" class in which the clock transmits gun orders direct to the guns. It does not calculate and transmit deflections to the director for onward transmission to the guns

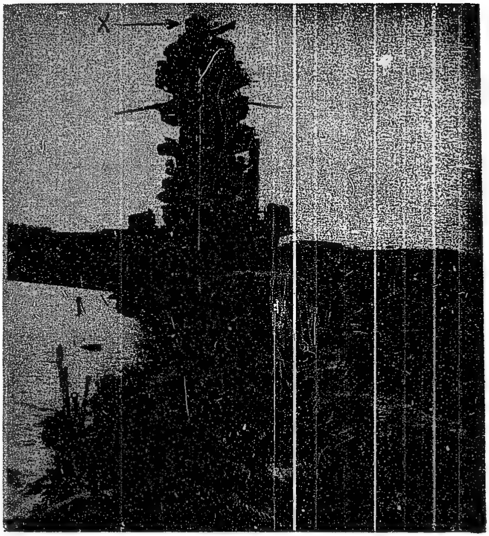


Figure 15

BATTLESHIP ISE TYPE 94 DIRECTOR

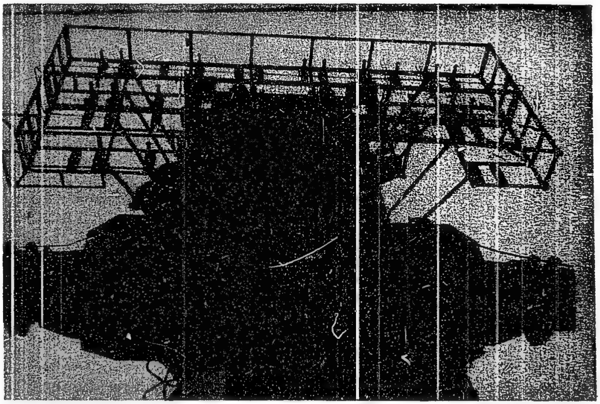


Figure 16

BATTLESHIP ISE RADAR ANTENNAE AND RANGE FINDER

Figure 17
BATTLESHIP ISE LOOKING AFT

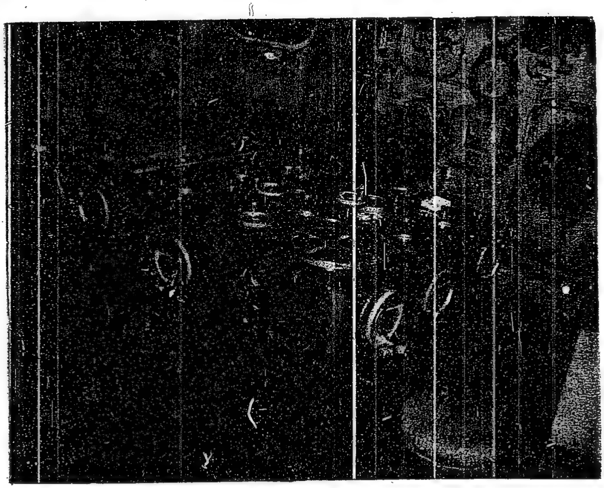


Figure 18
TYPE 94 L.A. CLOCK (SHAGEKIBAN)

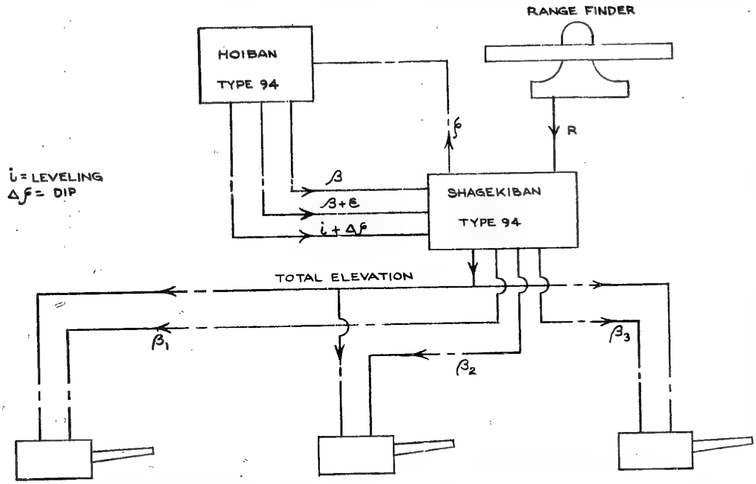


Figure 19

TYPE 94 DIRECTOR (HOIBAN) AND TYPE 94 CLOCK (SHAGEKIBAN)

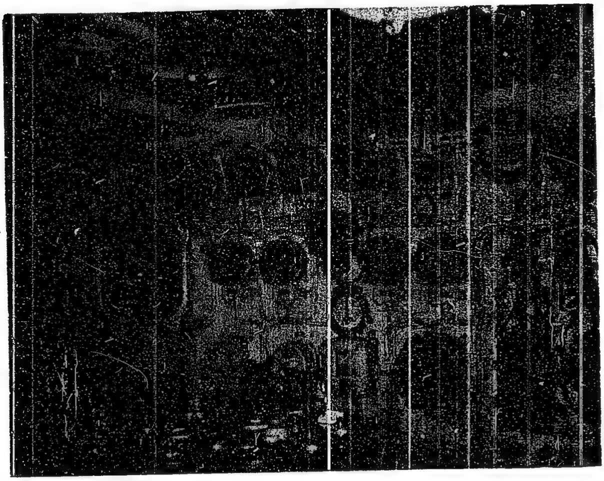


Figure 20

SECONDARY ARMAMENT PLOTTING ROOM ON NAGATO

("reciprocal"). Figure 19 shows diagram for director clock and guns.

The system was seen installed complete and undamaged in BB NAGATO and is shown in Figures 18, 20 and 23. In Figure 20 the range averaging device (a rectangular box at the left hand side) can be seen; the other bulkhead instruments are conventional.

2. Type 94 Clock (SHAGEKIBAN)

In addition to the remarks above, the following points are of interest. There is only one automatic follow-up, and this is a pneumatic one on the range input from the range averaging device. This pneumatic servo system is taken from the Brown Compass Follow-up; it operates smoothly with little hunting, and since it is an exact copy of the Brown unit, no illustrations are given here.

In order to give a short analysis of the system, a schematic diagram (Figure 21) was prepared and the following refers:

a. Range System

$$\text{Future Range } R_1 = R + \int\frac{dR}{dt} + \Delta R + \Delta R' + R_c$$

Where R = Initial range and $R + \int\frac{dR}{dt}$ is present range

ΔR = Range difference due to own speed
$\Delta R'$ = Range difference due to target speed
R_c = Range correction

The present average range from one or all rangefinders and radar is followed up as already described, and transmitted to the plot. (In the case of BB ISE, Figure 16 shows a mattress type antenna for ranging only, stated to be 1.5 meters wave length and good for 170,000 meters. There is also a 10cm radar installation in ISE for range and bearing, but it was stated that the accuracy for bearing was very poor).

Range Rate $\frac{dR}{dt}$ is composed of two parts; i.e., own ship's speed and target speed. The own speed rate component, $V \cos B$, is obtained from own ship's speed resolvers, and target speed rate component is obtained by following up on the range rate turning handwheel which aligns a slit of light (through a simple lens system) tangentially with the range plot. Range difference due to own ship's speed is given by:

$$\Delta R = V \cos B \frac{\tan\phi}{\tan\omega} \frac{R_1}{V_t \cos\phi}$$

Where ϕ = Angle of sight
ω = Angle of descent
V_t = Muzzle velocity

This function differs only slightly from the ballistic function for wind deflection, and it can therefore be assumed:

$$\frac{\tan\phi}{\tan\omega} \frac{R_1}{V_t \cos\phi} = K \left(\frac{T}{R_1} - \frac{1}{V_t \cos\phi}\right)$$

$$\Delta R = K' V \cos B \left(\frac{T}{R_1} - \frac{1}{V_t \cos\phi}\right)$$

Where K and K' are constants for conversion to the units used.
Range difference due to target speed:

$$\Delta R' = v \sin\theta \cdot T$$

Where θ = target angle

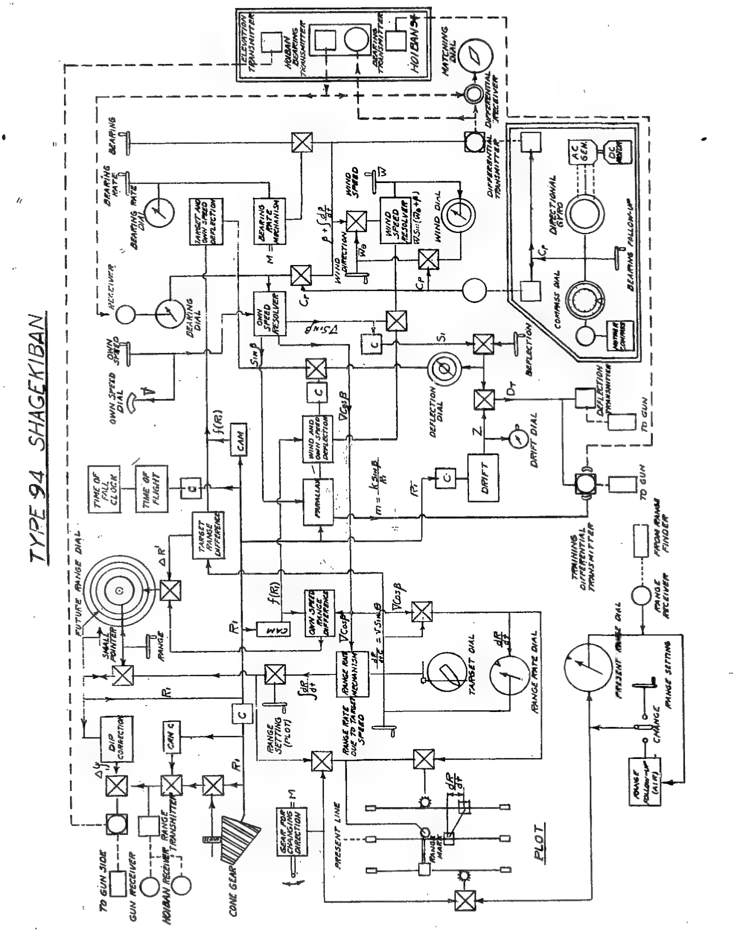


Figure 21

TYPE 94 L.A. CLOCK (SHAGEKIBAN) DIAGRAM

b. Super Elevation and Dip

These quantities are obtained by plate cams and are shown in the schematic diagram, Figure 21.

c. Deflection System

$$\text{Total deflection } D_T = S + D + E + Z + D_c$$

Where S = Deflection due to own ship's speed
D = Deflection due to target speed
E = Deflection due to wind
Z = Deflection due to drift
D_c = Deflection due to spotting correction
v = Target speed
V = Own ship speed
θ = Target inclination
B = Target bearing

$$S = \frac{V \sin B}{V_t \cos \phi}$$

$$D = v \cos \theta \frac{T}{R_1}$$

$$E = W \sin (B + W_\theta) \left(\frac{T}{R_1} - \frac{1}{V_t \cos \phi}\right)$$

$$Z = f (R_1)$$

Where W = Wind velocity, and W_θ - Wind direction
From this we get:

$$S + D + E = (v \cos \theta + V \sin B) \frac{T}{R_1} + [W \sin (B - W_\theta) - V \sin B] \left(\frac{T}{R_1} - \frac{1}{V_t \cos \phi}\right)$$

Both these terms are solved separately and added differentially. Bearing rate is expressed by $\frac{dB}{dt} = \frac{v \cos \theta \pm V \sin}{R}$, and wind and own ship's speed by $W \sin (B + W_\theta) \pm \sin B$. This is obtained by adding the outputs of the resolvers of own ship's speed and wind.

d. Total Training Transmissions

The total training is as follows:

$$B_1 = B + D_t + \Delta B + m_1$$

Where B = Present bearing
ΔB = Cross level dorrection to training
m_1 = parallax correction for any number of batteries

e. Number of Personnel

Figure 22 shows the position of the operators whose tasks are as follows:

Operator No. 1 Range setting and range rate due to target speed
Operator No. 2 Future range, own speed, wind speed and direction settings
Operator No. 3 Bearing angle and bearing rate follow-up
Operator No. 4 Deflection follow-up
Operator No. 5 Control officer

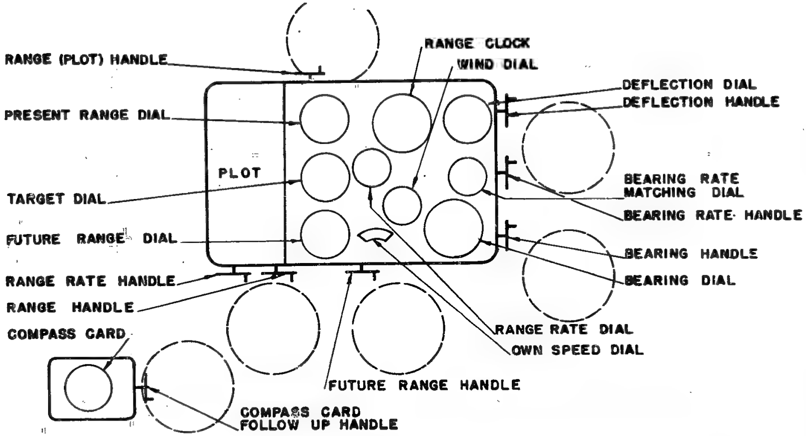


Figure 22
TYPE 94 L.A. CLOCK. PERSONNEL

Figure 23
COMPASS FOLLOW-UP

f. Weights and Sizes

Total weight .... 4.25 kg
Length .... 0.8 meters
Height .... 0.9 meters
Width .... 0.6 meters

g. Limits (for the 12.7cm 50 cal gun)

Measured range .... 20,000 meters
Gun range .... 15,000 meters
Left deflection .... 120 mils (L.A.)
Right deflection .... 90 mils (L.A.)
Left and Right deflections ..... 250 mils (H.A.)
Own speed .... 40 knots
Enemy speed .... 40 knots

It will be noticed that one of the limits in the parentheses refer to H.A. The equipment was designed only for L.A., but approximate deflections are applied for barrage fire against torpedo bombers.

h. Compass Follow-Up

Figure 23 shows a box in the plotting room of NAGATO. This box is almost completely empty save for a simple follow-up from the navigational compass. It was the intention to develop a special fire control compass, but the war terminated before designs were perfected.

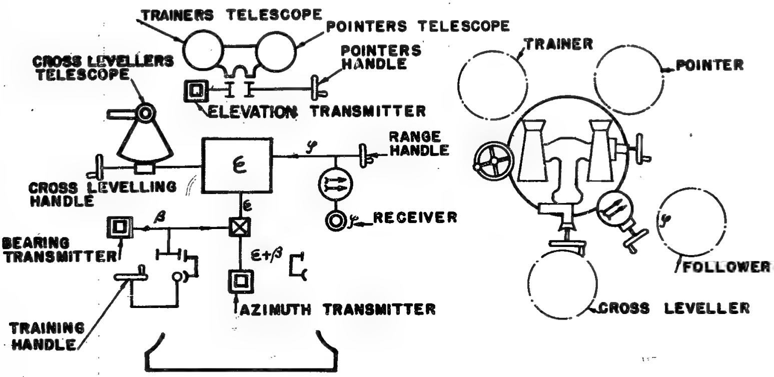


Figure 24
TYPE 94 DIRECTOR (HOIBAN) SCHEMATIC DIAGRAM

3. Type 94 Director (HOIBAN)

This low angle director for secondary batteries of capital ships and main director of light cruisers differs in the following respects from the main battery directors of the same type.

a. No parallax correction mechanisms; mention has already been made of this in the description of the SHAGEKIBAN.

b. Cross roll correction to training is added differentially in the SHAGEKIBAN so that the director telescopes remain undisturbed.

c. No spotting telescope for the control officer. A simple schematic diagram shows this director in Figure 24.

C. L.A. FIRE CONTROL SYSTEM FOR DESTROYERS TYPE 94 COMPUTER (BIODOBAN) AND TYPE 94 DIRECTOR (HOIBAN)

1. General

The four main types of fire control systems in Japanese Destroyers are as follows:

a. HOIBAN (old type) plus BIODOBAN Type 94, Mod 1 L.A.

b. HOIBAN Type 94 plus BIODOBAN Type 94, Mod 2 L.A.

c. HOIBAN Type 2 plus BIODOBAN Type 2 H.A./L.A.

d. KOSHA SOCHI Type 94 (class: AKITSUKI) H.A.

The systems in (c) and (d) above have already been described in NavTechJap Report, "Japanese Anti-Aircraft Fire Control", Index No. O-30, but as for (a) and (b), the only difference between them is that (a) belongs to the reciprocal type (already described in SHAGEKIBAN Type 92 and SHAGEKIBAN Type 94), and (b) belongs to the series type. There were no destroyers available having (b) system, nor any documents or drawings. The only information available was from interrogations.

It is a good L.A. system for small ships, being better than the H.A./L.A. HOIBAN Type 2 and BIODOBAN Type 2 for surface fire when the latter is in L.A., but the former is strictly limited to surface fire. The director (HOIBAN) is identical to the HOIBAN Type 94 already described for the main armament control. Figure 25 shows a damaged director in cruiser AOBA (trainer's side).

2. Type 94 Computer (BIODOBAN)

a. This computer or clock (Figure 26 shows the layout) is a tachymetric or rate measuring device, and provides future range and total deflection as follows:

(1) Future Range $R_1 = R + \int \frac{dR}{dt} + R_{1c}$, where R_{1c} represents all other corrections for range.

(2) Total Deflection $D_T = S + Z + D_c$, where S is own speed correction and is equal to $\frac{V \sin B}{V_t}$ and Z equals drift, D_c being all corrections to deflection. Figure 27 is a simplified schematic diagram showing the main characteristics of this computer.

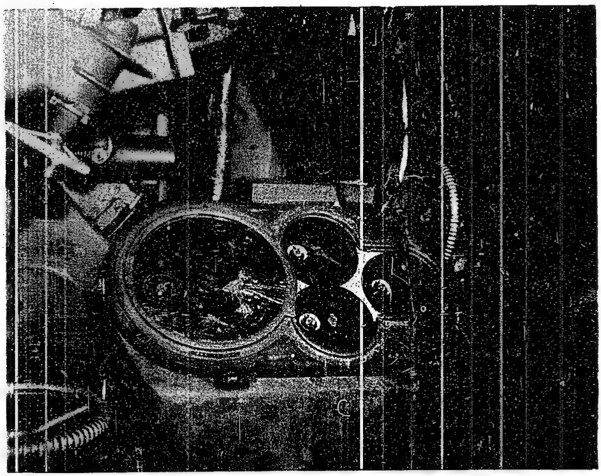


Figure 25
TYPE 94 DIRECTOR (HOIBAN) INSTALLED IN CRUISER AOBA

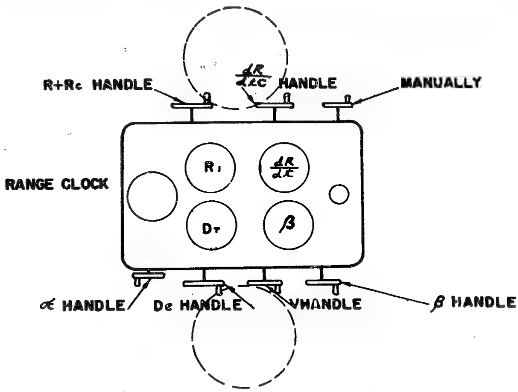


Figure 26
TYPE 94 L.A. CLOCK (BIODOBAN) DIAGRAM

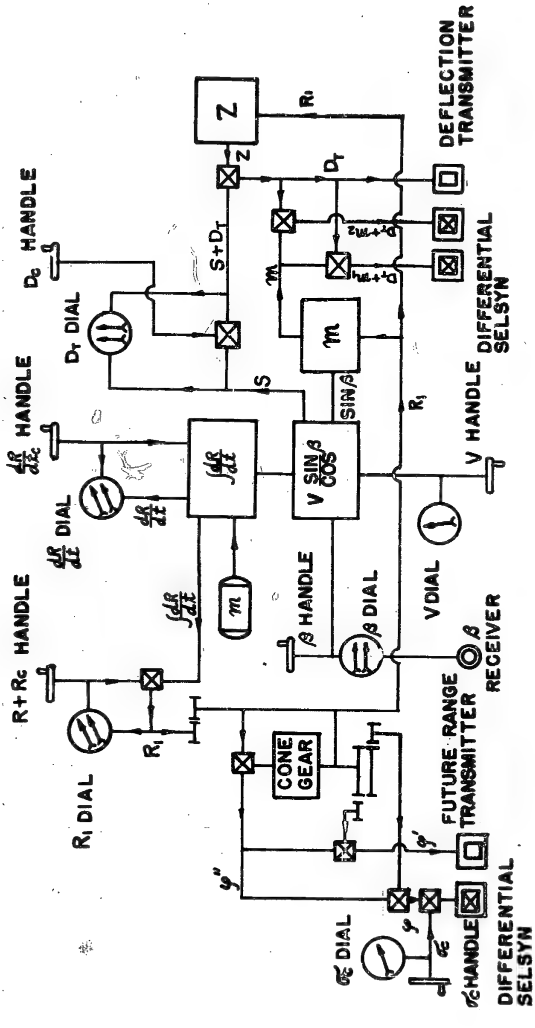


Figure 27

TYPE 94 CLOCK (HIODOHAN) DIAGRAM

b. Limits

Range .... 20,000 meters
Gun range .... 19,800 meters
Range rate .... 80 knots L. A. and 300 knots crude H.A. setting
Own speed .... 40 knots
Enemy speed .... 40 knots

The BIODOBAN is prepared for two sets of ballistics 15cm/50 cal and 14cm/50 cal.

c. Weight and Sizes

Weight .... 1.2 kg
Height .... 0.9 meters
Width .... 1.3 meters
Length .... 0.75 meters

D. L.A. FIRE CONTROL SYSTEMS IN BB's YAMATO AND MUSASHI TYPE 98 DIRECTOR (HOIBAN) AND TYPE 98 CALCULATING TABLE (SHAGEKIBAN) AND TYPE 98 SOKUTEKIBAN

The main armament fire control systems for these two battleships represented the very latest ideas of the Japanese fire control experts, naval officers, and designers.

The system consists of a director (HOIBAN), the calculating table (SHAGEKIBAN), in the transmitting station or plotting room and finally the SHOKUTEKIBAN, which (as already described in the Type 92 system) has no equivalent in the British and American Navies, but is an integral part of the Japanese L.A. fire control system for providing target course and speed.

This SOKUTEKIBAN Type 98 carries out the same functions as the SOKUTEKIBAN Type 92, but it takes a different form. Instead of being a sort of director in appearance, it is an appendage to the SHAGEKIBAN, receiving data from the director and transmitting it to the calculating table.

The transmissions from the calculating table are gun training and quadrant elevation. The system conforms to the conventional "series" arrangement (in contrast to the "reciprocal" arrangement as in destroyers: HOIBAN obsolete plus BIODOBAN Type 94).

2. Type 98 Director (HOIBAN)

a. The director tower is completely enclosed, and the optics of the various operators are of the periscope variety, protruding through the roof of the director. Since such importance is placed by the Japanese on optics (due in some degree to poor radar), they are listed as follows:

Operator No. 1 Layer .... Main telescope
Back horizon sight

Operator No. 2 Trainer .... Main telescope
Searcher sight

Operator No. 3 Control officer .... Main telescope
Searcher sight

Operator No. 4 Cross leveller .... Sight

Since all sights are rigidly fixed to the structure of the tower, the prisms only are moved (as in the U.S. Mark 37 system). The maximum elevation for these sights is 45° and the maximum depression angle 12°.

b. Measurements

Height	2.3 meters
Width	0.6 meters
Working circle	1.3 meters
Weight	3.5 metric tons

3. Type 98 Calculating Table (SHAGEKIBAN)

a. As seen from Figure 28, this equipment is in three main portions:

(1) Own ship's and target speed resolvers and bearing rate calculator; the dials show these quantities:

C_p - Compass course
B - True bearing
V - Own ship's speed
v - Target speed
R_o - Range spotting and correction
T_a - Target dial

(2) Wind speed resolver, deflection, and range difference calculator; the dials on this section show:

L - Latitude
t_p - Temperature and humidity
R_d - Range difference
D_r - Range day to day correction
W - Wind
V_t - I.V.
T - Time of flight
(S_p - Time of flight clock)

(3) Tangent elevation, parallax correction calculator, range and bearing plots, training and elevation transmissions; the dials show:

B_c - Azimuth correction
D_T - Deflection
R_c - Range correction
R - Future range
Rmo- Mean present range correction
F - Super elevation
D_p - Dip

The special features of this calculating table are the automatic follow-ups which, up until the time of its design, had been lacking in nearly all Japanese fire control. The particular follow-up used was an electro-mechanical type designed by the Aichi Clock Company, who also manufactured the table. A full description of this device is given in Part IV of this report.

b. Calculated Quantities

Range $R_1 = R + \frac{dR}{dt} + T_1\frac{dR}{dt} + R_c + \Delta R + \Delta R' + \Delta R_W + \Delta R_V + \Delta R\Omega + \Delta R_r + R_{ic}$

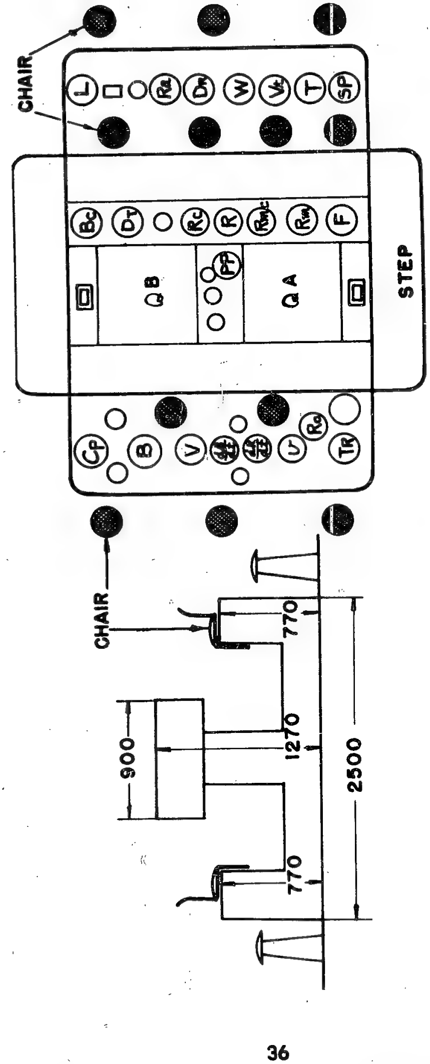


Figure 28
TYPE 98 CALCULATION TABLE (SHAGERIBAN)

Where R_1 = Future range
R = Initial range
T_1 = Elapsed time required for obtaining present range
R_c = Spotting correction
ΔR = Own ship's speed correction
$\Delta R'$ = Target speed correction
ΔR_W = Wind correction
ΔR_V = I.V. correction due to gun erosion
$\Delta R\Omega$ = Correction due to earth's rotation
ΔR_ρ = Barometric and ballistic corrections
R_{ic} = Day to day correction

For own ship's, target, and wind speed correctors there are two sets of multiplying devices:

$$\Delta R + \Delta R' + \Delta R_W = (V \cos B + v \sin \theta)\, f_1 (R_1) + [\, W \cos(W_\theta - \mu) + v \sin \theta\,]\, f_2 (R_1)$$

and for the terms ΔR_V, ΔR_ρ and $\Delta R\Omega$ there are independent calculating devices.

Lateral Deflection

$$D_T = S + D + E + Z + C + D_c$$

Where D_T = Total deflection
S = Own ship's speed deflection
Z = Drift
D = Target speed deflection
E = Wind deflection
G = Deflection due to earth's rotation
D_c = Spotting

For own ship's target and wind deflections, there are again two sets of multiplying devices, thus:

$$(V \sin B + v \cos \theta) f_3(R_1) + [\, W \sin (W_o - \mu) + v \cos \theta\,]\, f_4(R_1)$$

$$\text{now } v \sin \theta = \frac{dR}{dt} - V \cos B$$

$$\text{and } v \cos \theta = R \left(\frac{dB}{dt} - \frac{V \sin B}{R}\right)$$

In these equations $\frac{dR}{dt}$ and $\frac{dB}{dt}$ are obtained from the plot, $V \cos B$ is the output of own ship's speed resolver, and $\frac{V \sin B}{R}$ is the output of own ship's speed bearing rate calculator. These two quantities are transmitted to the target resolver linkage where their intersection point represents target inclination and speed.

c. <u>Limits</u>

Measured range .... 50,000 meters
Gun range .... 41,300 meters
Maximum deflection .... Right 130 mils, Left 160 mils
Deflections in azimuth .... 500 mils
Own ship speed .... 35 knots
Enemy ship speed .... 40 knots
Wind speed .... 40 meters/sec

d. <u>Measurements</u>

Maximum length .... 3.5 meters
Maximum height .... 1.5 meters
Weight .... 7.5 metric tons

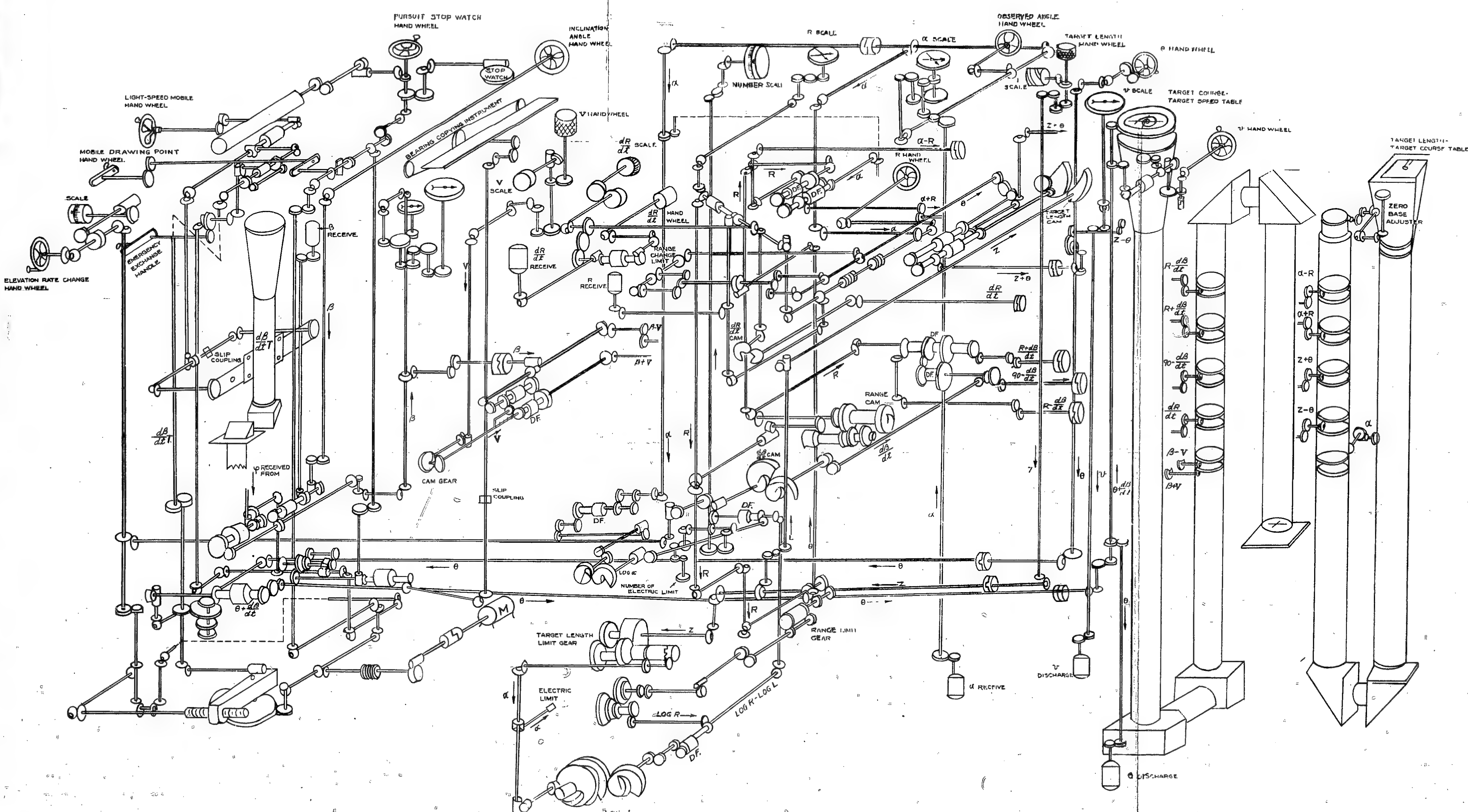


Figure 29
TYPE 98 SOKUTEKIBAN DIAGRAM

4. Type 98 SOKUTEKIBAN

a. The schematic diagram of the SOKUTEKIBAN is given in Figure 29. The SOKUTEKIBAN solves the following equations for target speed and inclination:

$$\frac{L \cos \theta}{R} = \alpha \text{ - - - - - - - - - - - - - } (1)$$

$$\frac{dR}{dt} = v \sin \theta + V \cos B \text{ - - - } (2)$$

$$R\frac{dB}{dt} = v \cos \theta + V \sin B \text{ - - - } (3)$$

Where L = Target length
R = Present range
α = Inclination angle
v = Target speed
V = Own ship speed
θ = Target inclination
B = True bearing
$\frac{dR}{dt}$ = Range rate
$\frac{dB}{dt}$ = Bearing rate

From equation (1) above target bearing is obtained, but equations (2) and (3) above are solved vectorially; i.e., $V\frac{dR}{dt}$ and $R\frac{dB}{dt}$ are added together vectorially and v and θ are obtained. The method adopted for solving these equations is an optical one. The diagram in Figure 30 shows how this is done. In this diagram, two deflecting prisms A and A' are rotated in opposite directions, causing the light spot on the screen to move along the diameter DD in proportion to the cosine of the rotation of the prisms. The rotation of the prisms is arranged as a function of L, R and α so that the equation is thereby satisfied.

All inputs to the SOKUTEKIBAN are by power selsyn and transmissions of v and θ are made by selsyn to the SHAGEKIBAN.

b. Measurements

Length	1.0 meter
Width	0.9 meters
Height	0.8 meters
Weight	0.6 kg

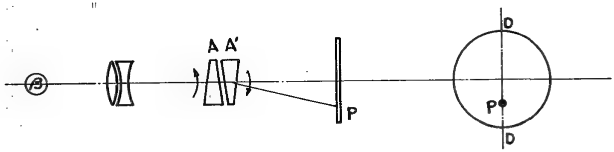


Figure 30

TYPE 98 SOKUTEKIBAN OPTICAL ARRANGEMENT

Part III
STABLE ELEMENTS AND STABLE VERTICALS

A. A BRIEF ANALYSIS OF RESEARCH IN THE JAPANESE NAVY ON GYROS

1. Type 98 Gyro Horizon

The research on the gyro horizon (for stable vertical) for the Japanese Navy was commenced in 1932 under the guidance of Rear Admiral (Tech) S. NITA, and the first endeavor was to stabilize a prism of a gun sighting telescope by a simple pendulous gyro (diameter 13cm). In early experimental models many errors of construction were found, such as bad design of gimbals, incorrect damping arrangements, and large errors due to linear accelerations from roll or alteration of course. From these early experiments, the Type 98 emerged and was finally tried out in 1935 in battleship HIEI, which was used for many experimental purposes. There are no drawings, schematics or anything else, all having been destroyed; but the diagram Figure 31 has been made from seeing the equipment and from discussions with Mr. TAKEMURA, a research worker associated with the institute.

The only figures available are as follows, and it is not known how reliable they are:

Diameter of gyro wheel	30.5cm
Speed of gyro wheel	8600 RPM
Angular momentum	2.87×10^9 abs units
Accuracy of settling	10'
Errors of roll and pitch	10'
Follow up errors at sensitive side	7'
Total follow up errors	15'
Period of undamping	60 min
Period of damping	65 min
Damping ratio	0.5

The follow-up mechanism, fed from the amplifier, provided a measure of roll and this was transmitted to the L.A. director for removing roll in the line of sight.

The worst features of this model were hunting in the follow-up, and gimbal friction. Figure 32 is a photograph of this equipment.

2. Type 1 Gyro Horizon

As a direct result of the shortcomings in the Type 98, referred to above, Type 1 was produced under the same guidance as Type 98 (Rear Admiral S. NITA), but with the addition of Lt. Cmdr. FUJITA and Mr. G. OTA. This was a great improvement on the previous instrument; the follow-up was better and the gyro was air supported.

This equipment was originally installed in aircraft carrier SHINYO, removed to KURE, and thence to the Technical Research Institute in TOKYO, where it survived the bombing. Figure 33 shows diagramatically the salient features; the three photographs (Figures 34, 35 and 36) show the general appearance.

In size it is equivalent to the U.S. stable element Mark VI, and the number of subsidiary components is also approximately the same except for the addition of the calculation mechanism which weighs approximately 1000 pounds and stands about four feet high. The only figures available are as follows:

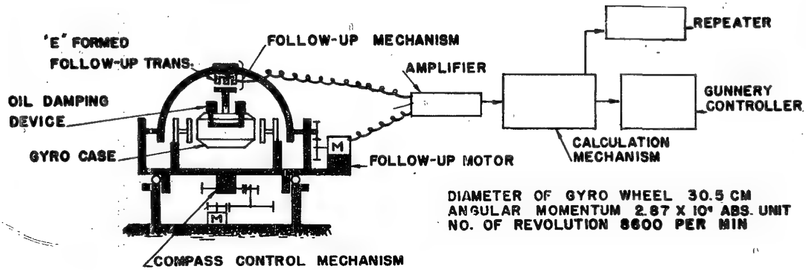


Figure 31
TYPE 98 GYRO HORIZON DIAGRAM

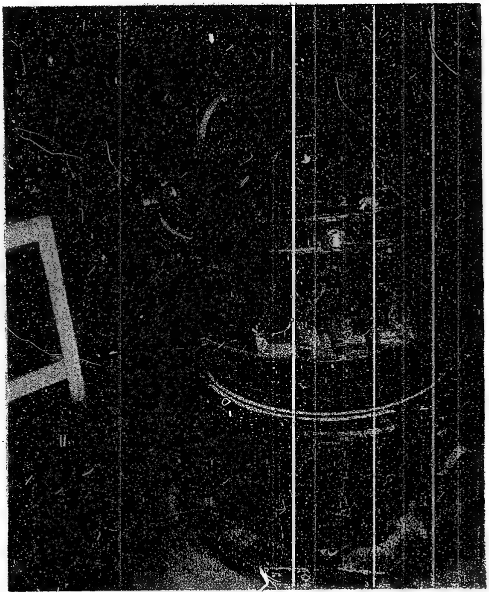


Figure 32
TYPE 98 GYRO HORIZON CASING

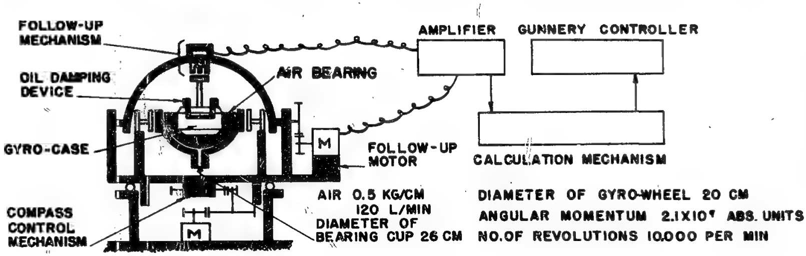


Figure 33
TYPE I GYRO HORIZON COMPONENTS DIAGRAM

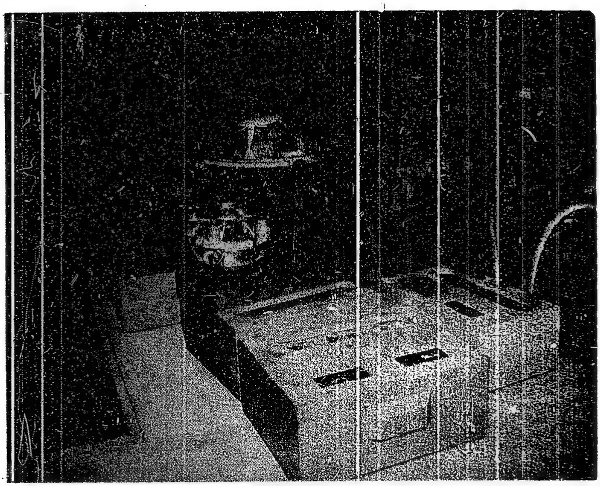


Figure 34
TYPE I GYRO HORIZON COMPONENTS

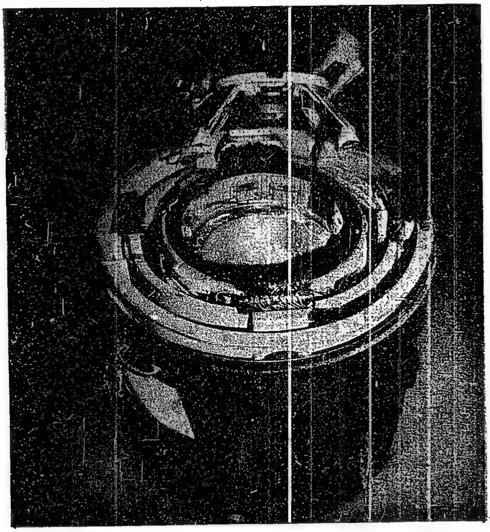


Figure 35
TYPE I GYRO HORIZON COMPONENTS

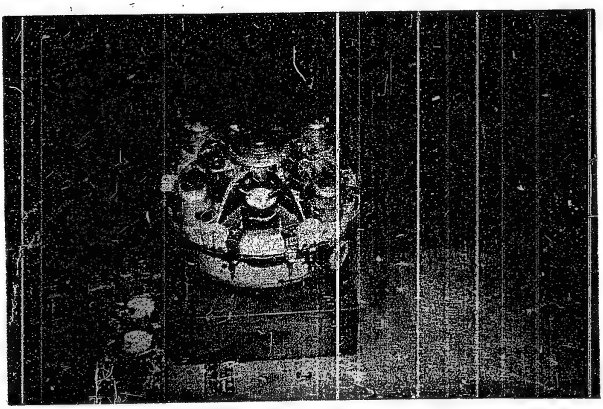


Figure 36
TYPE I GYRO HORIZON COMPONENTS

Diameter of gyro wheel 25cm
Speed of gyro wheel .... 10,000 RPM
Angular momentum .... 2.1×10^9 abs units
Air bearing support, dia. of cup 26cm
Air pressure .... 0.5 kg/cm^2
Accuracy of settling ....±3'
Period of undamping .... 60 min
Period of damping .... 65 min
Damping ratio 0.35
Errors of pitch and roll .... ±2'
Errors of follow up mechanism ....±2.5'
Total errors including transmission ....±5'

The calculating mechanism (see Figure 37) receives director setting and director training, roll and cross roll (relative to a true compass bearing) from the gyro horizon, and transmits roll and cross roll corected for D/S training to the director. There, by matching pointers, the operators apply the necessary data for roll in the line of sight and cross roll for indirect fire.

This equipment was designed originally for L.A. fire for main batteries of capital ships, but was applicable also for dual purpose guns of medium caliber.

The complete system was considered too complicated, and Japan's industrial capacity too limited, for production of these units.

3. Type 4 Gyro Horizon

This equipment is comparatively simple. It is designed as an aid to stabilization for AA control rather than a complete stabilization system, and depends to a great extent upon the skill of the operator.

It consists primarily of a vertical gyro (see Figure 38) with a mirror mounted on the top. This can just be seen in Figure 39. The gyro is suitably supported, and a spot of light is reflected from the mirror onto a screen with crosswires. This can be seen at the top right in Figure 40. The operator holds two large handles and follows the spot of light by moving the entire instrument, thereby following-up the gyro. By this action he transmits roll and cross roll to the director where these values can be followed-up by hand and used instead of the horizon. It will be seen that there are two hand follow-ups and the results are not very good. Refer to Figure 41. Details are as follows:

Diameter of gyro wheel 8cm
Moment of inertia .... 10^4 gr cm^2
Angular momentum .... 2.2×10^9 gr cm^2/sec
Speed of wheel .... 20,000 RPM
Damping coefficient characteristics
(i.e., time taken for gyro to settle from a displacement of 1.5°)
Accuracy of settling .... 1.5'
Accuracy of stabilization .... 25' (destroyer)

Figure 42 shows the crude resolver and transmitters, and Figure 43 shows the instrument installed in destroyer HANAZUKI in the plotting room.

4. Horizon With Air Supported Spherical Gyro

This research project consisted of a sphere supported on an air cushion, that had an electro magnetic rotating field for providing the rotating force, and at the same time, a vertically rotating field as a damping

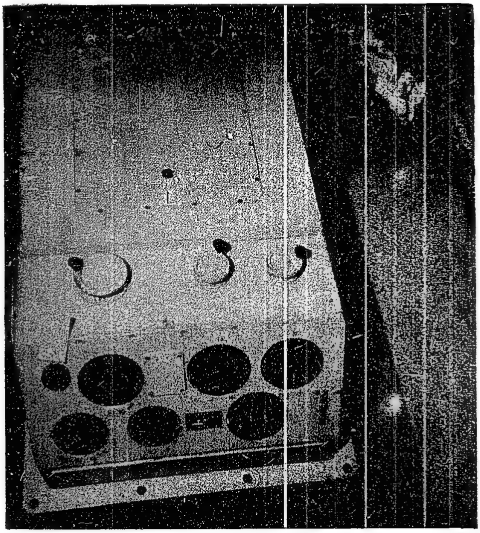


Figure 37
TYPE I GYRO CALCULATING BOX

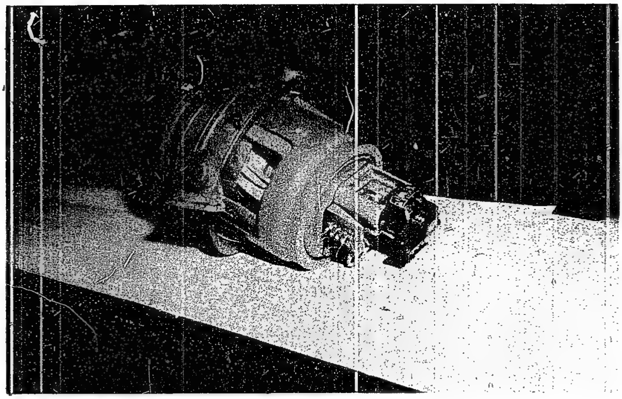


Figure 38
TYPE 4 GYRO HORIZON GYRO

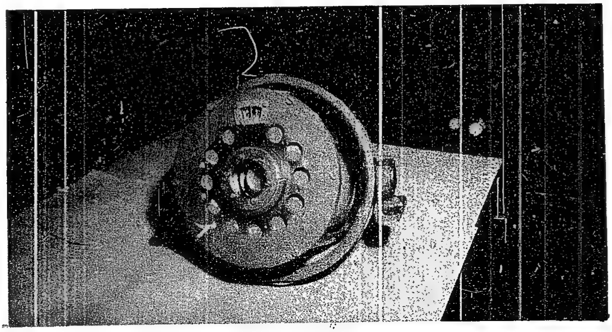


Figure 39
TYPE 4 GYRO HORIZON GYRO

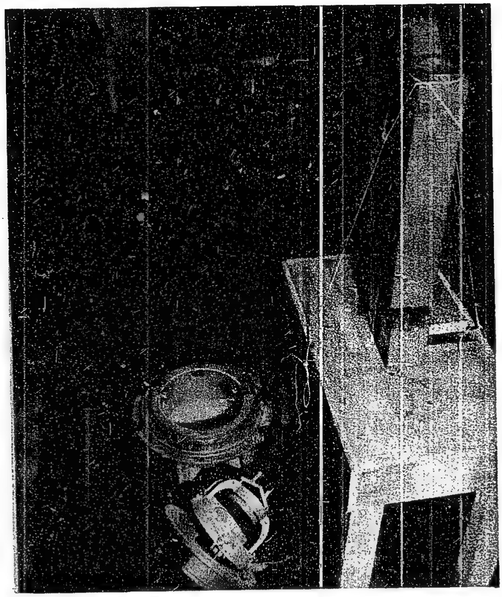


Figure 40
TYPE 4 GYRO HORIZON SCREEN

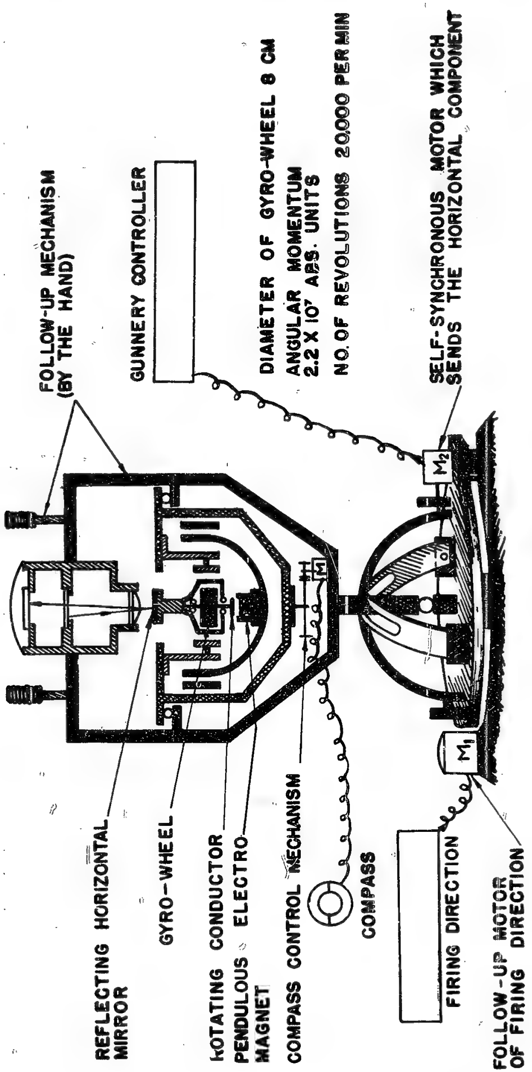


Figure 41
TYPE 4 GYRO HORIZON DIAGRAM

Figure 42
TYPE 4 GYRO HORIZON RESOLVER

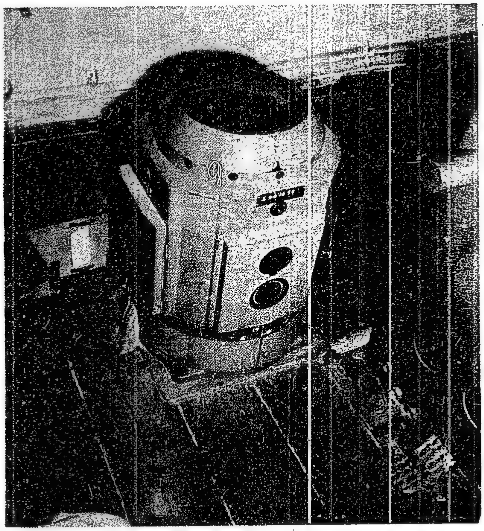


Figure 43
TYPE 4 GYRO HORIZON CASING

device. This spherical gyro is slightly bottom heavy and the damping force varies as the displacement of the sphere from its vertical position. In this way the damping control is a minimum with minimum displacement. The diagram in Figure 44 shows the device without any mechanism for compass follow-up or gyro follow-up. (The equipment was completely destroyed in an air raid on 15 April 1945 before the final features could be added). The accuracy required was 2.5' of arc for all conditions of roll and pitch and this figure was obtained on trial just before the equipment was destroyed. Details are as follows:

Diameter of gyro sphere 13cm
Moment of inertia .... 5×10^4 gr cm^2
Angular momentum .... 10^8 gr cm^2/sec

5. Gyro Horizon-Dual Stabilizer

Figures 45 and 46 show a scheme attempting to use rate of turn gyros with one degree of freedom each for stabilization.

The equipment consists of two large gyros with axes parallel, rotating in opposite directions. The scheme was copied from a German stabilization system for small machine gun mounts. The gyro system is precessed by roll and cross roll components, and provides training and elevation corrections for the sight and gun for present position data. The gun deflections are supplied separately from a calculating mechanism and added differentially by means of electrical differentials. Details are as follows:

Diameter for gyro wheel 11cm
Moment of inertia of gyro wheel .... 5.4×10^4 gr cm^2
Speed of gyro wheel .... 20,000 RPM
Accuracy of settling .... 1'
Settling from 5^o displacement .... 1 min
Errors due to pitch and roll .... 3'

6. Gyro Horizon Type K 7 - H 3

This equipment was developed towards the end of the war, but so promising were the experimental models that orders were placed for castings for production units similar to the prototype.

This device is shown in the sketch (Figure 47). Its merit lies in the fact that friction with the rotating pivot is removed by rotating the pivot at the same speed as the gyro. Thus, relative to the pivot, there is no friction of a rotating nature. Certain interference harmonics resulted and the voltage in the lower coil was increased from 50 to 70 volts to overcome this trouble. This treatment was successful and the vibration trouble was overcome. The apparatus is very much as shown in the sketch.

There is no apparent provision for the effects of gun shock; for this reason the equipment is being forwarded for further investigation.

The equipment is shown in Figure 48, and there was no additional gear for transmission of the quantities measured. Apparently only level and cross level values were sought, and if so, the sensitive unit is small in size. Details are as follows:

Diameter of gyro wheel 5.6cm
Moment of inertia .... 1500 gr cm^2
Speed of Wheel .... 10,000 - 20,000 RPM
Accuracy of settling .... 0.5'
Rolling error .... 1'
Amplitude .... 13.5^o in 9 secs
Total weight .... 2.5 kg

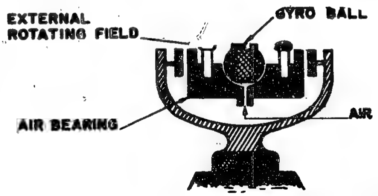


Figure 44
SPHERICAL GYRO HORIZON

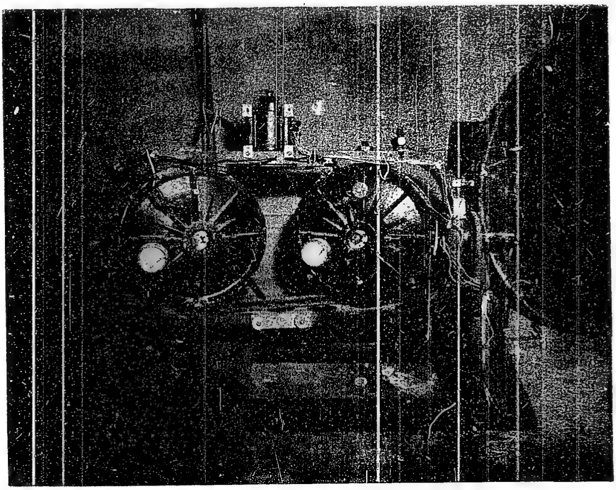


Figure 45
GYRO HORIZON STABILIZER

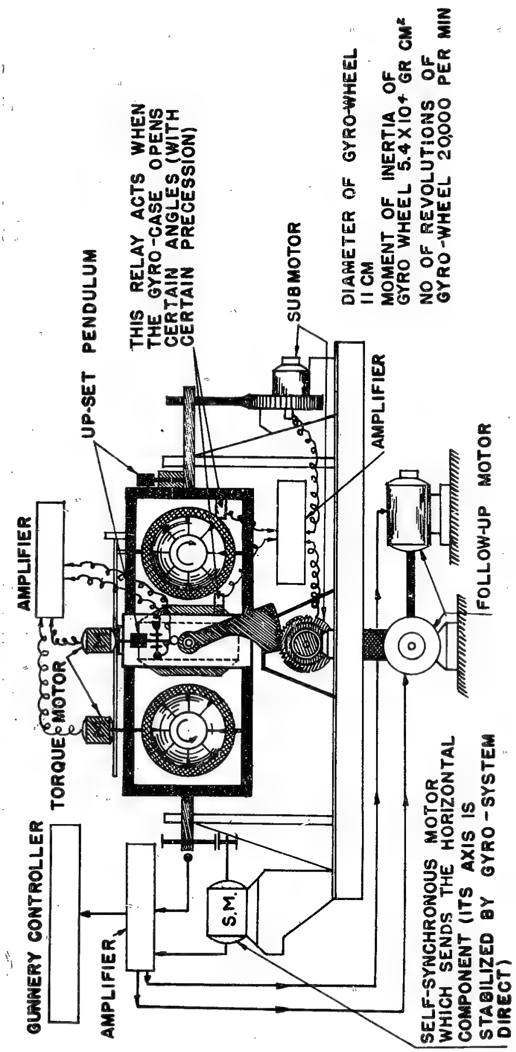
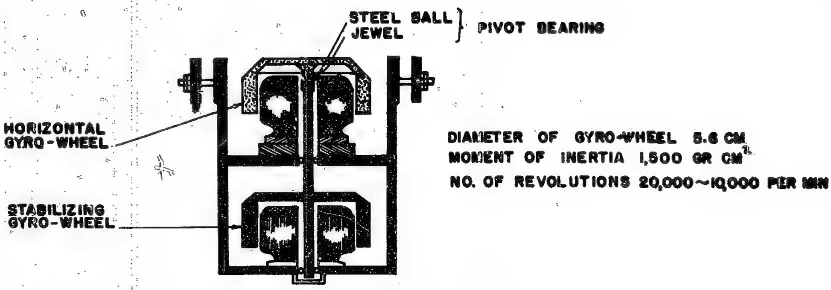


Figure 46
GYRO HORIZON STABILIZER DIAGRAM



THIS HORIZON IS THE DIRECT TYPE.
IF YOU WANT TO SEND THE HORIZONTAL COMPONENT TO ANY REQUIRED POSITION, ADEQUATE FOLLOW-UP MECHANISM MUST BE ADDED.

Figure 47
GYRO HORIZON K7-H3 DIAGRAM

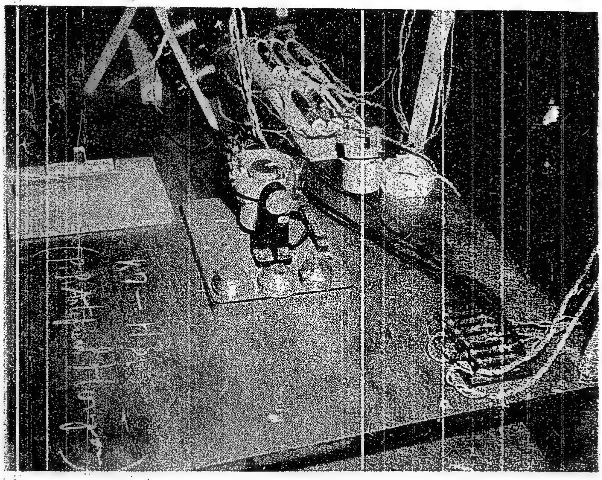


Figure 48
GYRO HORIZON K7-H3 GENERAL VIEW

7. Other Research

In the Naval Research Technical Laboratories there were some other experimental gyro systems, but all with reference to gyro compass research. No vital points of interest have been brought to the fore by these Japanese scientists whose main contribution has been in detail rather than in original studies.

Part IV
SERVO MECHANISMS AND TRANSDUCTORS

A. GENERAL

There are four types of follow-ups used for fire control purposes in the Japanese Navy.

1. Mechanical

The friction torque amplifier or F.A. torque amplifier. This power follow-up system in Japanese fire control gear is an exact copy of the American Bethlehem Torque Amplifier. The Japanese design was taken from the American Machinist Magazine in 1928 (no record of the month). It is equally similar to the British Admiralty Research Laboratory's Mechanical Torque Amplifier.

This torque amplifier is founded on the "capstan" principle and the increments of power produced therefrom are small smooth increments dependent upon the slipping of a band on a drum. (This definition is emphasized for purposes of comparison with Type 4 to be discussed later.)

2. Electric Torque Amplifier

A sample of this well-known device has been shipped to the Ordnance Investigating Laboratory (refer to Enclosure (A), and there are several other samples in the Type 94 KOSHA SOCHI (High Angle Computer) described in NavTechJap Report, "Japanese Anti-Aircraft Fire Control", Index No. O-30. It consists of two magnetic clutches on each side of a driven plate identical to the Ford Instrument Company's power follow-up of the original Mark 94 director.

3. Pneumatic Follow-up

Reference has already been made to this device in this report under the heading "Type 94 L.A. Clock (SHAGEKIBAN)", (Part II, B, 2). It is an exact replica of the Brown Compass Follow-up. So far as it is known, it is only used for the single application cited, viz., the range follow-up in the Type 94 SHAGEKIBAN.

4. Electro-Mechanism Follow-Up

a. Description - This device does not appear to be a straight copy of any existing torque amplifier, although it has certain features reminiscent of many torque amplifiers.

Fundamentally, it is a mechanical device; the electrical components are only used to actuate what might be termed "valves". These are mechanical valves and can be further described as clutches or devices to take rotation from one member and transfer the rotation in small increments to other (output) members.

This torque amplifier is the most prominent feature of the Type 98 System in MUSASHI and YAMATO, and other modern vessels of which no samples remain. The Aichi Clock Company has destroyed their records (or all records were destroyed for them when the factory was demolished by bombing), and the following description has, therefore, been prepared from interrogations and sketches. The device must be considered in two separate parts; first, the regulator or the electrical component as shown in Figure 49 and 50, and, second, the follower which is the mechanical portion shown in Figure 51 and 52.

(1) Regulator

The same nomenclature is used in all the diagrams, and the operation of the device can be observed in each one in turn.

If A is the gear with internal teeth, B the pinion meshing with A, and C the "crank-like" shaft to which pinion B is attached and on which it rotates, then the locus of a point P is as shown in view (b) of Figure 49. Then, if n_1 be the number of teeth of gear A and n_2 be the number of teeth of gear B, and angle θ the angle through which C is turned, we have the situation when P once more meets the circumference:

$$\theta = 2 \frac{n_2}{n_1}$$

If next a pillar with contacts be mounted at P to operate contacts E, a type of very sensitive switch results. This switch causes an electro-magnet to attract a soft iron core to one side or the other, depending on the direction of rotation.

By suitable choice of the ratio $\frac{n_2}{n_1}$, the contact will be made only once for a brief instant of time until contact is again established. In this way the instrument acts as a very sensitive switch. Small mechanical energy has been converted to electrical energy and then back to a more powerful mechanical movement of an intermittent on-off type.

(2) Follower - This movement is transmitted by light linkages to "valves" or clutches which engage with circular plates O, P, Q. These plates are attached to gears E, F, and G driven by a constant speed motor. If the rotation of A is counterclockwise, B and D will be rotated in a clockwise direction; and if E is fixed with G and F free, then G and F will be rotated in a counterclockwise direction, as will H. Again, with F fixed and G and E free, then G and E will rotate clockwise and so will H, and so on. In other words, by determining the rotation of either E or F, the rotation of H can be reversed. In the central position with H stopped, E and F must be free with G fixed.

In operation, therefore, if B is rotated, either one of L or L' will be pushed outwards and the other pulled inwards by means of a spring. This movement causes one of the contacts P or P' to make and the other to break, so that either J or K is actuated. If the follow-up speed is slower than the input to the sensitive side, both magnets would be energized simultaneously if it were not for the fact that a fork or yoke M causes a rod N to keep open one or the other contact. This yoke M is therefore a kind of coarse control to ensure rotation in one direction or the other until the speed of the follower exceeds that of the sensitive side.

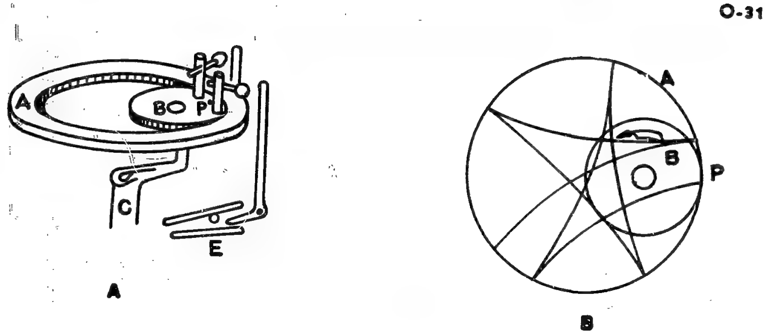


Figure 49
ELECTRO-MECHANICAL TORQUE AMPLIFIER (REGULATOR)

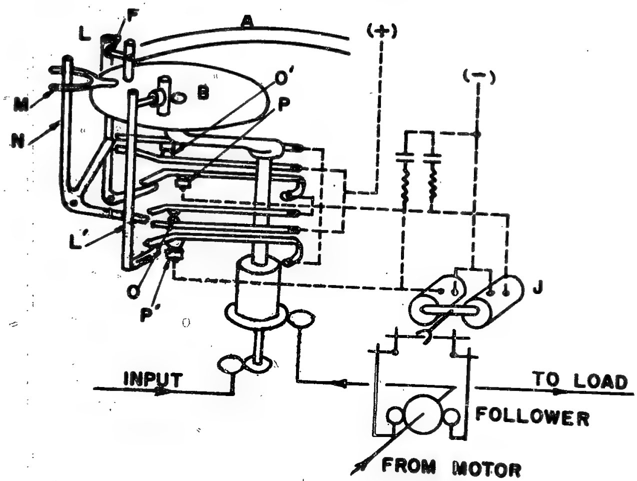


Figure 50
ELECTRO-MECHANICAL TORQUE AMPLIFIER (REGULATOR)

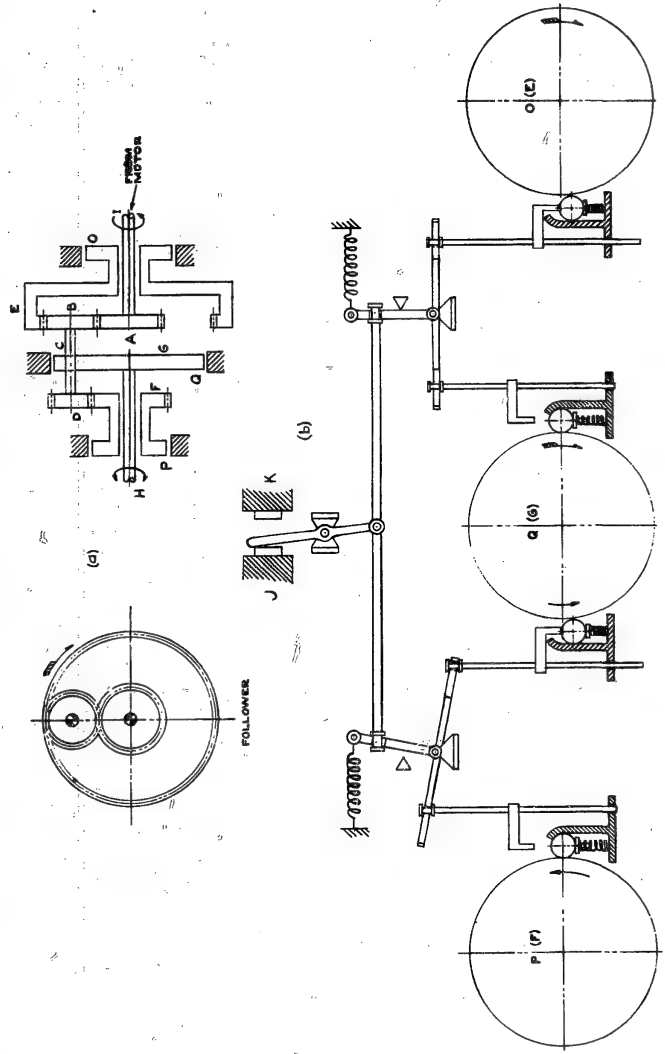


Figure 51
ELECTRO-MECHANICAL TORQUE AMPLIFIER (FOLLOW-UP)

B. CHARACTERISTICS OF THE MECHANISM

The worst feature of the mechanism is that the follower, in theory, is always going in jumps; the reason is that there is no slippage as in the capstan type of torque amplifier described in Part IV A 1, but instead, the follower is struggling always to go at the same speed as the discs O, P and Q, or alternatively to be stopped.

This follow-up, therefore, is not a smooth copy of the input, and is only smoother than it is in theory by virtue of the inertias involved. However, inertias must not be unduly increased as violent hunting would result.

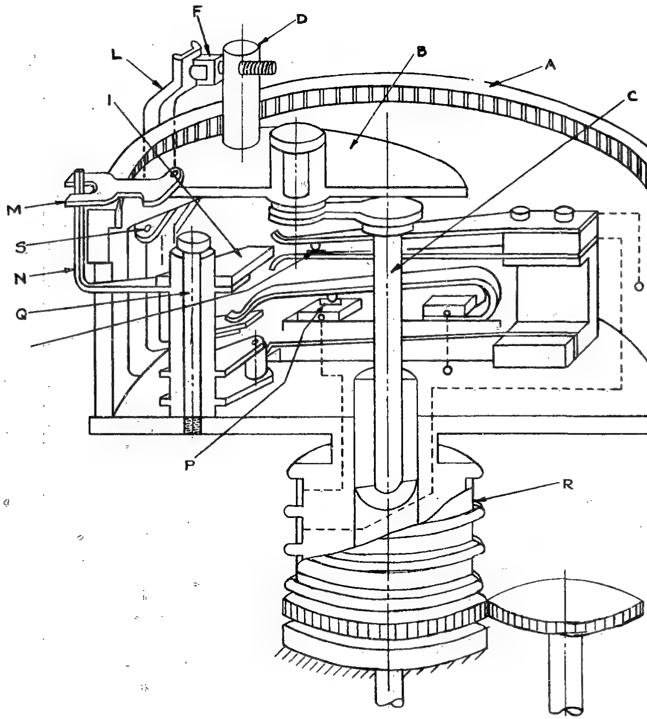


Figure 52
ELECTRO-MECHANICAL TORQUE AMPLIFIER (FOLLOW-UP)

ENCLOSURE (A)

LIST OF EQUIPMENT SENT TO ORDNANCE INVESTIGATION LABORATORY
NAVAL POWDER FACTORY INDIAN HEAD MARYLAND

NavTechJap No.	Item
JE50-3016	Type K7-H3 Artificial Horizon
JE50-3018	Magnetic Clutch Torque Amplifier
JE50-3019	Sensitive Element Type 4 Gyro Horizon
JE21-3407	Firing Time Instrument - NAGATO
JE21-3408	Firing Time Instrument - NAGATO
JE21-3409	Firing Time Separator - NAGATO

* * * * *

ENCLOSURE (B)

LIST OF DOCUMENTS FORWARDED TO WDC THROUGH ATIS

NavTechJap No.	Item	ATIS No.
ND21-3427	Torque Amplifier	3944
ND21-3436	Reduction of Dispersion	3952
ND21-3437	Projectile Dispersion	3953
ND21-3438	Dispersion Reports	3954
ND21-3439	Dispersion Charts	3955
ND50-3011	Gun Sight L.A. very early type	3912
ND50-3012	Notes on Type 92 SHAGEKIBAN	3913
ND50-3014	SOKUTEKIBAN Type 92	3915
ND50-3016	Notes on SHAGEKIBAN Type 92	3889
ND50-3017	SHAGEKIBAN Type 92 (MOGAMI Class)	3890
ND50-3018	HOIBAN Type 97 HIEI (Similar to YAMATO)	3891
ND50-3019	HOIBAN Type 94 (Battleship)	3892

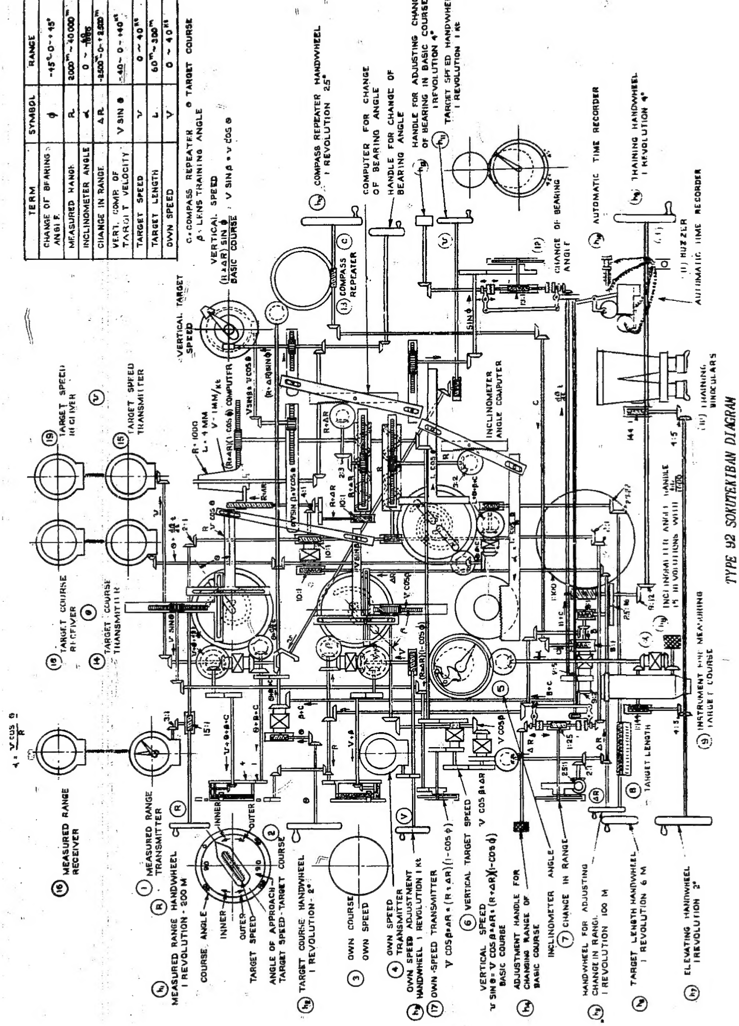
ENCLOSURE (C)

NOMENCLATURE CHART

YAMATO Class	45cm	Type 98 HOIBAN Type 98 SHAGEKIBAN	15.5cm	Type 98 HOIBAN Type 98 SHAGEKIBAN	12.7 40 Cal	Type 94 KOSHASOCHI	
NAGATO Class	40cm	Type 94 HOIBAN Type 92 SHAGEKIBAN	14cm	Type 94 HOIBAN Type 94 SHAGEKIBAN	12.7 40 Cal	Type 94 KOSHASOCHI	
FUSO, KIRI- SHIMA Class	36cm	Type 94 HOIBAN Type 92 SHAGEKIBAN	15cm	Type 94 HOIBAN Type 94 SHAGEKIBAN	12.7 40 Cal	Type 94 KOSHASOCHI	
Heavy Cruiser (over 7000 tons)	20cm	Type 94 HOIBAN Type 92 SHAGEKIBAN			12.7 40 Cal	Type 94 KOSHASOCHI	among them (AA Gun 12cm)
Light Cruiser	14cm	Type 94 HOIBAN Type 94 SHAGEKIBAN					
Aircraft Carrier	12.7 40 Cal	Type 94 KOSHASOCHI					among them (AA Gun 10cm Type 98)
Destroyer	12.7 and 50 Cal	HOIBAN old Type BIODOBAN Type 94					L.A.
	12.7 and 50 Cal	HOIBAN Type 94 BIODOBAN Type 94					L.A.
	12.7 and 50 Cal	HOIBAN Type 2 BIODOBAN Type 2					H.A. & L.A
	10cm Type 98	KOSHASOCHI Type 94					H.A. & L.A.

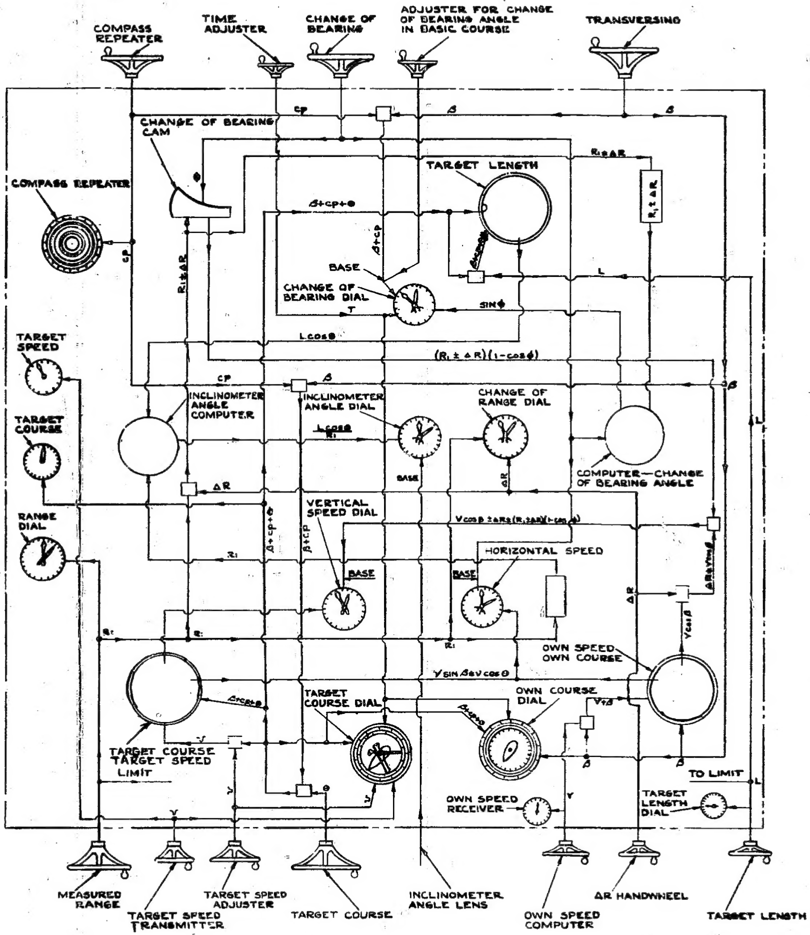
ENCLOSURE (D)

TERM	SYMBOL	RANGE
CHANGE OF BEARING ANGLE	ϕ	$-45°\sim 0 \sim +45°$
MEASURED RANGE	R	$2000^m \sim 40000^m$
INCLINOMETER ANGLE	α	$0 \sim \frac{40}{1000}$
CHANGE IN RANGE	ΔR	$-2500^m \sim 0 \sim +2500^m$
VERT. COMP. OF TARGET VELOCITY	V SIN θ	$-40 \sim 0 \sim +40^{kt}$
TARGET SPEED	v	$0 \sim 40^{kt}$
TARGET LENGTH	L	$60^m \sim 300^m$
OWN SPEED	V	$0 \sim 40^{kt}$



TYPE 92 SOKUTEKIBAN DIAGRAM

ENCLOSURE (D), continued



TYPE 92 SOKUTEKIBAN DIAGRAM